ENGINEER

international scientific journal

SPECIAL ISSUE

E-ISSN
3030-3893
ISSN
3060-5172

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A bridge between science and innovation

TOSHKENT DAVLAT TRANSPORT UNIVERSITETI
Tashkent state transport university

ENGINEER

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E-ISSN: 3030-3893

ISSN: 3060-5172

SPECIAL ISSUE

MARCH 27, 2026

engineer.tstu.uz

“WOMEN IN INNOVATION AND SCIENCE” XALQARO ILMIY-AMALIY KONFERENSIYA VA FORUMI ILMIY ISHLARI TO‘PLAMI

Toshkent davlat transport universitetida 2026-yil 27-mart kuni “Women in Innovation and Science” xalqaro forumi ilmiy ishlari to‘plami chop etildi.

Mazkur nufuzli tadbirlar O‘zbekiston Respublikasi Oliy ta’lim, fan va innovatsiyalar vazirligi hamda Transport vazirligi hamkorligida tashkil etilib, mamlakatimizda ilm-fan, innovatsiyalar va zamonaviy texnologiyalarni rivojlantirish, shuningdek xalqaro ilmiy hamkorlikni yanada kengaytirishga qaratilgan muhim platforma hisoblanadi.

Konferensiya ochilish marosimida davlat organlari, xalqaro tashkilotlar va yetakchi oliy ta’lim muassasalari vakillari ishtirok etdi. Jumladan, Toshkent davlat transport universiteti rektori G‘ulomov Abdulaziz Abdullayevich, O‘zbekiston Respublikasi Transport vazirligi vakili Ulmasova Lobarkhon Adilovna, Osiyo taraqqiyot banki eksperti Claire Charamnac, Istanbul Aydin universiteti vasiylik kengashi raisi Mustafa Aydin, Belarus davlat transport universiteti rektori Kazakov Nikolay Nikolayevich hamda Qirg‘iziston Respublikasi Transport vazirligi vakili Dinara Moldokalieva ishtirok etdilar.

Konferensiya ilmiy dasturi doirasida plenar va panel sessiyalar, shuningdek ilmiy ma’ruzalar taqdimoti o‘tkazilib, ularda sun’iy intellekt va raqamli texnologiyalarni iqtisodiyot va ta’limga joriy etish, transport va aviatsiya sohasida innovatsion yechimlar, sanoat va IT sohasida texnologiya transferi, shuningdek ta’limda raqamli platformalar va intellektual tizimlar kabi dolzarb masalalar yoritildi.

2026-yil 27-mart kuni o‘tkazilgan “Women in Innovation and Science” xalqaro forumi ayollar yetakchiligi, innovatsiyalar va STEM sohalariga bag‘ishlangan bo‘lib, mamlakatimizda ayollarning ilm-fan va texnologiya sohalaridagi ishtirokini kengaytirish, ularning yetakchilik salohiyatini rivojlantirish hamda xalqaro hamkorlikni mustahkamlashga qaratilgan strategik maydon sifatida tashkil etildi.

Forum doirasida ayollar yetakchiligini rivojlantirish va rag‘batlantirish, xalqaro tajriba almashinuvi va ilmiy tarmoqlarni kengaytirish, yosh tadqiqotchi ayollar va PhD talabalarni qo‘llab-quvvatlash hamda innovatsion ekotizimlarda gender tenglikni ta’minlash kabi ustuvor vazifalar amalga oshirildi. Shuningdek, forumda ayollar yetakchiligi va STEM, gender tenglik va ilm-fan institutsional rivoji, ayollar tadbirkorligi va innovatsion startaplar, innovatsiya ekotizimlari va xalqaro hamkorlik, yosh ayol tadqiqotchilarni rivojlantirish, mentorlik va akademik tarmoqlar yo‘nalishlarida tematik sessiyalar tashkil etildi.

Forumda davlat organlari, xalqaro tashkilotlar, yetakchi oliy ta’lim muassasalari va ilmiy markazlar vakillari, jumladan “OLIMA” uyushmasi raisi Murtazayeva Raxbar Hamidovna, “Sharq ayoli” xalqaro ayollar jamoat fondi raisi Tursunbayeva Saodat Gafurovna, Osiyo taraqqiyot banki eksperti Claire Charamnac, O‘zbekiston Respublikasi Transport vazirligi vakili Ulmasova Lobarkhon Adilovna, Toshkent davlat transport universiteti rektori G‘ulomov Abdulaziz Abdullayevich, Qirg‘iziston Respublikasi Transport vazirligi vakili Dinara Moldokalieva hamda Indoneziyadan universitet dekani Yoga Prihatin ishtirok etdilar.

Shuningdek, forumda Yevropa va Osiyo davlatlaridan yetakchi olimlar, ekspertlar va yosh tadqiqotchilar keng qatnashdi.

Forum dasturiga ochilish marosimi, panel muhokamalar, ilmiy chiqishlar hamda professional rivojlanish bo‘yicha workshoplar kiritilgan bo‘lib, ular doirasida gender tenglik, ayollar karyerasini rivojlantirish, ilmiy tadqiqotlar va innovatsion boshqaruv bo‘yicha amaliy seminarlar tashkil etildi.

Mazkur tadbirlar Osiyo taraqqiyot banki (ADB), “OLIMA” — O‘zbekiston xotin-qizlar olimlari uyushmasi, “Sharq ayoli” xalqaro ayollar jamoat fondi, Germaniya xalqaro hamkorlik jamiyati (GIZ), shuningdek Rossiya, Turkiya, Indoneziya va Qirg‘iziston oliy ta’lim muassasalari hamda Belarus Milliy fanlar akademiyasi ilmiy institutlari hamkorligida o‘tkazildi.

Mazkur xalqaro ilmiy-amaliy konferensiya va forumning ahamiyati shundaki, ular xalqaro ilmiy hamkorlikni mustahkamlash, innovatsion ishlanmalarni amaliyotga joriy etish, raqamli va barqaror rivojlanishni ta’minlash, shuningdek ayollarning ilm-fan va innovatsiya sohalaridagi rolini kuchaytirishga xizmat qiladi. Shu bilan birga, mazkur tadbirlar yosh olimlar va tadqiqotchilarni qo‘llab-quvvatlash, ilmiy tajriba almashish hamda global ilmiy makonga integratsiyalashuvni jadallashtirishda muhim ahamiyat kasb etadi.

Mazkur xalqaro ilmiy-amaliy konferensiya va forumning maqsadi zamonaviy ilmiy tadqiqot yo‘nalishlarini muhokama qilish, innovatsion yondashuvlar va ilg‘or texnologiyalar bo‘yicha ilmiy natijalar almashuvini ta’minlash, shuningdek xalqaro ilmiy hamkorlikni rivojlantirishdan iboratdir.

Tadbirda O‘zbekiston Respublikasi hamda xorijiy mamlakatlarning oliy ta’lim muassasalari va ilmiy-tadqiqot institutlari olimlari, shuningdek amaliyotda muhim natijalarga ega bo‘lgan mutaxassislar o‘z ilmiy ishlari bilan ishtirok etdilar.

Ushbu ilmiy to‘plamda muhandislik, transport, raqamlashtirish, sun’iy intellekt, innovatsion boshqaruv, gender tenglik va barqaror rivojlanish sohalarida faoliyat yuritayotgan yetakchi olimlar, professor-o‘qituvchilar va tadqiqotchilarning ilmiy ishlari jamlangan. To‘plamda dolzarb ilmiy muammolar, zamonaviy yechimlar, nazariy va amaliy tadqiqot natijalari yoritilib, ushbu yo‘nalishlarning bugungi holati va istiqboldagi rivojlanish tendensiyalari aks ettirilgan.

Mazkur nashr mamlakatimizda ilm-fan va innovatsion rivojlanishni ta’minlash, xalqaro ilmiy aloqalarni mustahkamlash hamda yosh olimlar va tadqiqotchilarni qo‘llab-quvvatlash yo‘lidagi muhim qadamlardan biri sifatida e’tirof etiladi.

Shuningdek, mazkur ilmiy to‘plamda keltirilgan natijalar kelgusida ilmiy tadqiqotlar samaradorligini oshirish, amaliyotga yo‘naltirilgan innovatsion yechimlarni keng joriy etish hamda sohalararo integratsiyani chuqurlashtirish uchun muhim ilmiy asos bo‘lib xizmat qiladi. To‘plam materiallari nafaqat ilmiy jamoatchilik, balki ishlab chiqarish sohasi mutaxassislari, doktorantlar va talabalar uchun ham foydali manba hisoblanadi.

Mazkur nashrda yoritilgan ilmiy g‘oyalar va ilg‘or yondashuvlar asosida yangi ilmiy izlanishlar olib borilishi, xalqaro ilmiy aloqalarning yanada rivojlanishi hamda innovatsion rivojlanish strategiyalarining takomillashishiga xizmat qilishi kutilmoqda.

"WOMEN IN INNOVATION AND SCIENCE" XALQARO FORUM TASHKILIY QOʻMITASI

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Extensive application and characteristic properties of mastic asphalt concrete

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Abstract: This article presents the properties, advantages, and applications of mastic asphalt concrete. The application methodology of mastic asphalt concrete is analyzed based on the example of Japanese practice. In addition, the standard properties of bitumen, as well as the standard characteristics of bitumen used in mastic asphalt mixtures, are described. Target values for penetration and Luehr flow of the mastic asphalt mixture are also provided. Recommendations for the use of the Luehr flow diagram and the specific aspects of mastic asphalt production are discussed. For road pavements in areas with dense traffic and a tendency toward plastic flow (deformation), the target values of penetration are specified.
Keywords: mastic asphalt concrete, steel bridge, penetration, flowability, pavement, “compliance domain.”

Quyma asfaltbetonning keng qo‘llanilishi va o‘ziga xos xususiyatlari

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Annotatsiya: Ushbu maqolada quyma asfaltbetonning xususiyatlari, ustunliklari va qo‘llanilishi bayon etilgan. Quyma asfaltbetonning qo‘llanilish usuli Yaponiya tajribasi misolida tahlil qilingan. Bundan tashqari bitumning standart xususiyatlari, quyma asfaltbeton qorishmasi uchun ishlatiladigan bitumning standart xususiyatlari, quyma asfaltbeton aralashmasining penetratsiya va Lyuer oquvchanligining maqsadli qiymatlari keltirib o‘tilgan. Lyuer oquvchanligi grafigini qo‘llash bo‘yicha tavsiyalar, quyma asfaltbetonni tayyorlashning o‘ziga xos jihatlari tahlil qilingan. Plastik oqimga (deformatsiyaga) moyil bo‘lgan va transport harakati zich bo‘lgan hududlardagi yo‘l qoplamalari holatida, penetratsiyaning maqsadli ko‘rsatkich qiymatlari ko‘rsatib o‘tilgan.
Kalit so‘zlar: quyma asfaltbeton, metall ko‘prik, penetratsiya, oquvchanlik, qoplama, “muvofiqlik maydoni”.

1. Kirish

Quyma asfaltbeton-“Gussasphalt” (GA) lotincha “Gu” so‘zidan olingan bo‘lib, dastlab “daryo” degan ma’noni anglatadi va keyinchalik “quyilayotgan va oqayotgan” degan ma’noni anglatadi. Bu quyma asfaltbetonning yaxshi suyuqlikka ega ekanligini va shunchaki yotqizish va tekislash orqali, hech qanday katok ishlatmasdan amalga oshirish mumkinligini ko‘rsatadi[1].

Quyma asfaltbeton qoplamasi Germaniyada paydo bo‘lgan va uzoq vaqtdan beri qo‘llanilmoqda. Ko‘pgina loyihalar quyma asfaltbeton qoplamasi bilan bajariladi, bu o‘sha paytdagi eng ajoyib yechimlar ekanligi isbotlangan, masalan, Köln-Mülhaym Reyn ko‘prigi, Oberkasseler Briage, Mulhaym ko‘prigi. Keyinchalik u Buyuk Britaniya, Polsha, Daniya, Yaponiya, AQSh va boshqa rivojlangan mamlakatlarda keng qo‘llaniladi[2].

Quyma asfaltbetonning afzalliklari ko‘p bo‘lib ular quyidagilar:

1. Suv o‘tkazuvchanligi past

Quyma asfaltbetonning suv shimuvchanligi nolga yaqin. Shuning uchun, quyma asfaltbeton yo‘l qoplamasida mutlaqo suv o‘tkazmaydigan bo‘lib, boshqa turdagi zichlab yotqiziladigan asfaltbeton qorishmasiga qaraganda ancha yaxshi. Ko‘pgina hollarda, quyma asfaltbeton to‘g‘ridan-to‘g‘ri suv o‘tkazmaydigan material sifatida yoki gidroizolyatsiya tizimining bir qismi sifatida qo‘llaniladi.

2. Chidamlilik

Quyma asfaltbetonning bo‘shliq qismi juda kichik bo‘lganligi sababli, atrof-muhit namligi ichkaridan o‘tolmaydi. Natijada, namlik yoki havo tufayli ishlashning yomonlashishi va shikastlanishlarning, masalan, qoplama buzilishi, mo‘rtlashish va boshqalarning oldini olish mumkin. Shu maqsadda quyma asfaltbeton bardoshli hisoblanadi.

3. Egiluvchanlik va yoriqlarga chidamlilik.

Uzoq vaqt davomida transport va iqlim sharoitlariga duchor bo‘lishiga qaramay, quyma asfaltbeton qoplamasi yuqori bitum miqdori tufayli yaxshi egiluvchanlikni saqlab qolishi mumkin. U yorilish va delaminatsiya (bir-biridan ajralib ketishi) kabi shikastlanishlarsiz egilish deformatsiyasiga bardosh bera oladi.

4. Yaxlitlik.

Quyma asfaltbeton yotqizish jarayonida o‘z-o‘zidan tekislanadigan materiallar turiga kiradi. Ushbu xususiyat quyma asfaltbeton qoplamasining vertikal deformatsiyaga ma’lum darajada qarshilik ko‘rsatishiga va gorizontal tekislikda ancha kuchli birikishiga imkon beradi. Shunday qilib, u qoplamaning yaxshi yaxlitligini ta’minlaydi.

4. Ishlov berish natijasida hech qanday zararlanmaydi.

Shakl berish va mustahkamlikni oshirish jarayoni quyma asfaltbeton harorati pasaygandan so‘ng o‘z-o‘zidan sodir bo‘ladi. Ishlav berishni amalga oshirishning hojati yo‘q. Shunday usul qo‘llanilganda, asfaltbeton sifati buzilishiga olib keladigan muammolar (harorat notekisligi va chaqiqtosh ajralishi) deyarli yuz bermaydi[3].

Quyma asfaltbetondan bugungi kunda dunyoning ko‘plab yetakchi davlatlari balki, Yaponiya ham keng qo‘llamoqda.

Yaponlar quyma asfaltbetonni metal ko‘prik qoplamalarida keng qo‘llaydi, chunki u suv o‘tkazmaydi va egilishga yaxshi moslashadi.

Ular quyma asfaltbetonni o‘ziga xos usulda tayyorlashadi. Ular quyma asfaltbetonni Trinidad ko‘li asfalti yoki termoplastik elastomer bilan modifikatsiyalangan bitumni asfaltbetonga qo‘shish orqali ishlab chiqaradi va yirik to‘ldiruvchi, mayda to‘ldiruvchi yoki mineral to‘ldirgich bilan aralashtiradi. Ular zavodda aralashtiriladi va quyish uchun zarur bo‘lgan yuqori suyuqlikni olish uchun yuqori haroratda maxsus qozonda qoriladi[4].

2. Tadqiqot metodologiyasi

Yuqori haroratda ishlovchanlikni va plastik oqimga qarshilikni yaxshilash zarurati hisobga olinib, odatda ignaning botish chuqurligi 20–40° bo‘lgan neft bitumi Trinidad ko‘li asfaltbeton qoplamasi bilan aralashtirib ishlatiladi.

Trinidad ko‘li asfaltbeton qoplamasida bitumning miqdori odatda umumiy asfaltbeton qorishmasi miqdorining 8–10 % ini tashkil qiladi. Aralashtirilgandan keyin bitumning yumshash harorati 60°C dan yuqori bo‘lishi kerak.

Bitumga ignaning botish chuqurligi 20–40° bo‘lgan neft bitumi va Trinidad ko‘li asfaltbetonining standart xususiyatlari 1-jadvalda keltirilgan. Quyma asfaltbeton qorishmasi uchun aralashtirilgandan keyingi asfaltbetonning standart xususiyatlari 2-jadvalda ko‘rsatilgan.

1-jadval

Bitumning standart xususiyatlari[7]

Ko‘rsatkich	Birligi	Neft bitumi 20–40	Trinidad ko‘l asfalti
Ignaning botish chuqurligi	1/10 mm	20 – 40	1 – 4
Yumshash harorati	°C	55.0 – 65.0	93 – 98
Cho‘ziluvchanlik	sm	50 yoki undan ko‘p	–
Bug‘lanishdan keyingi massa yo‘qotishi	%	0.3 yoki undan kam	–
Trikloroetan ichida eruvchanlik	%	99.0 yoki undan ko‘p	52.5 – 55.5
Chaqnash harorati	°C	260 yoki undan ko‘p	240 yoki undan ko‘p
Zichlik	g/cm³	1.00 yoki undan ko‘p	1.38 – 1.42

2-jadval

Quyma asfaltbeton qorishmasi uchun ishlatiladigan bitumning standart xususiyatlari[7]

Ko‘rsatkich	Birligi	Standart qiymat
Ignaning botish chuqurligi (25°C)	1/10 mm	15 – 30
Yumshash harorati	°C	58 – 68
Cho‘ziluvchanlik (25°C)	sm	10 yoki undan ko‘p
Bug‘lanishdan keyingi massa yo‘qotishi	%	0.5 yoki undan kam
Trikloroetan ichida eruvchanlik	%	86 – 91
Chaqnash harorati	°C	240 yoki undan ko‘p
Zichlik	g/sm³	1.07 – 1.13

Quyma asfaltbeton uchun nisbatlar standart darajadagi agregat va asfaltbeton bilan qorishma tayyorlash hamda oquvchanlik va penetratsiya sinovlarini o‘tkazish orqali aniqlanadi.

Penetratsiya va oquvchanlik sinovlarining maqsadli qiymatlari 3-jadvalda ko‘rsatilgan.

3-jadval

Quyma asfaltbeton aralashmasining penetratsiya va Lyuer oquvchanligining maqsadli qiymatlari[7]

Ko‘rsatkich	Birligi	Maqsadli qiymat
Penetratsiya (40°C)	mm	Yuza qatlami 1–4
		Bog‘lovchi qatlam 1–6
Ryuer oquvchanligi (240°C)	soniya	3–20

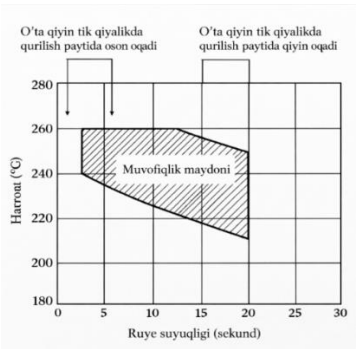
Agregatning standart granulometrik tarkibi va asfaltbeton miqdorining loyihaviy diapazoni 4-jadvalda ko‘rsatilgan.

4-jadval

Quyma asfaltbeton aralashmasining standart granulometrik tarkibi

Elak o‘lchami	Elakdan o‘tuvchi massa ulushi (%)
19 mm	100
13.2 mm	95 – 100
4.75 mm	65 – 85
2.36 mm	45 – 62
600 µm	35 – 50
300 µm	28 – 42
150 µm	25 – 34
75 µm	20 – 27
Bitum miqdori (%)	7 – 10

Plastik oqimga (deformatsiyaga) moyil bo‘lgan va transport harakati zich bo‘lgan hududlardagi yo‘l qoplamalari holatida, penetratsiyaning maqsadli ko‘rsatkichi 2 dan past bo‘lishi kerak. Bunday hollarda, ba’zan asfaltbeton bilan oldindan qoplangan 5-markali maydalangan tosh (chaqiqtosh) yuzaga yoyiladi va bosib zichlanadi. Plastik oqimga chidamlilikni tekshirish uchun ba’zan g‘ildirak izi sinovlari (wheel tracking tests) o‘tkaziladi.



1-rasm. Quyma asfaltbeton uchun Lyuer oquvchanligi grafigi

Ushbu rasm quyma asfaltbetonning harorati va uning oquvchanligi (Lüer fluidity) o‘rtasidagi bog‘liqlikni ko‘rsatadi. Bu grafik yo‘l qurilishida asfaltbetonni qaysi haroratda va qanday quyuqlikda ishlatish kerakligini aniqlash uchun juda muhim[7].

Grafikning asosiy o‘qlari:

Y-o‘qi: Harorat (°C). Bu yerda 180°C dan 280°C gacha bo‘lgan harorat ko‘rsatilgan.

X-o‘qi: Lyuer oquvchanligi (Lüer fluidity, sec). Bu asfaltbetonning qanchalik tez oqishini soniyalarda o‘lchaydi.

Eslatma: Soniya qancha kam bo‘lsa (chapga qarab), asfaltbeton shuncha suyuq bo‘ladi. Soniya qancha ko‘p bo‘lsa (o‘ngga qarab), asfaltbeton shuncha quyuq bo‘ladi.

Shtrixlangan maydon bu “maqbul oraliq” hisoblanadi. Ya’ni, ish sifatli chiqishi uchun asfaltbetonning harorati va oquvchanligi aynan shu shtrixlangan hudud ichida bo‘lishi kerak. Masalan, harorat 240°C bo‘lganda, oquvchanlik taxminan 5 dan 18 soniyagacha bo‘lishi kerak.

Maxsus holatlar (Yuqoridagi ikkita kichik katak): Chapdagi katak (Easy to flow): Tik qiyaliklarda asfaltbeton oson oqishi kerak bo‘lsa, u suyuqroq (5-8 soniya oralig‘ida) tutiladi. O‘ngdagi katak (Hard to flow): Agar qiyalikda asfaltbetonning juda tez oqib ketmasligi (bir joyda turishi) kerak bo‘lsa, u quyuqroq (13-18 soniya oralig‘ida) tutiladi.

Grafikdan ko‘rinib turibdiki, harorat qanchalik yuqori bo‘lsa, asfaltbetonning oquvchanligi shunchalik yaxshilanadi (soniyalar kamayadi). Qurilishda yo‘lning qiyaligiga qarab, ushbu grafik asosida kerakli harorat tanlanadi.

Quyma asfaltbetoni zavodda isitish va issiqlik izolyatsiyasi bilan jihozlangan kuher (maxsus isitish qurilmasi) yordamida qorishtiriladi va tashiladi. Kuher qorishmaning ajralib ketishiga (segregatsiyaga) yo‘l qo‘ymagan holda, haroratni oshirib, qorishmani bir tekisda qorishtirish imkoniyatiga ega bo‘lishi kerak.

Qurilish jarayonida yuqori oquvchanlik va yopishqoqlikni ta’minlash uchun kuherda quyma asfaltbetonni yetarli darajada qorishtirish muhimdir. Shuning uchun qorishma mikserdan chiqarilgandan so‘ng darhol kukerga joylanishi va kamida 40 daqiqa davomida qorishtirilishi kerak. Qorishma uzoq vaqt qorishtirishni talab qilganda, sifat o‘zgarishiga yo‘l qo‘ymaslikka e’tibor qaratish lozim[5].

Kuherdan chiqarilgan qorishma ixtisoslashtirilgan quyma asfaltbeton finisheri yordamida yotqiziladi va tekislanadi. Sirpanishga chidamlilikni, ishqalanishga (yeyilishga) bardoshlilikni va plastik oqimga chidamlilikni oshirish maqsadida, qorishma tekislangandan so‘ng darhol yuzaga oldindan (asfaltbeton bilan) qoplangan maydalangan tosh yoyiladi va po‘lat halqali rinka (valik) bilan bosib zichlanadi. Oldindan qoplangan maydalangan tosh, aralashmaning haroratiga qarab, ba’zan o‘z og‘irligi ostida cho‘kishi mumkin va yuzada qoladigan tosh miqdori turlicha bo‘lishi mumkin. Yoyish ishlari imkon qadar bir xil haroratda amalga oshirilishi kerak. Qorishmani yotqizgandan keyin ko‘pchiklar (pufakchalar) paydo bo‘lishining oldini olish uchun asosiy qatlam yuzasi yetarlicha quritilishi va moy kabi kirlardan tozalanadi. Qurilish jarayonida yog‘ingarchilik va kondensatsiya kabi ob-havo sharoitlariga alohida e’tibor berish lozim.

Quyma asfaltbeton qatlamining qalinligi odatda 3 dan 4 sm gacha bo‘lishi kerak. Quyma asfaltbeton bevosita beton asosga yotqizilganda, qoplama yuzasi ostidan chiquvchi suv bug‘lari hisobiga ko‘pchiklar hosil bo‘lishi mumkin. Buning oldini olish uchun oddiy asfaltbeton tekislovchi qatlam yotqizilishi mumkin.

Zarracha hajmi 4,75 dan 2,36 mm gacha bo‘lgan, oldindan qoplangan maydalangan tosh miqdori taxminan 8 kg/m² bo‘lishi kerak. 13,2 dan 4,75 mm gacha va 19 dan 13,2 mm gacha bo‘lgan o‘lchamlar uchun esa taxminan

8-15 kg/m² bo‘lishi lozim. Oldindan qoplangan maydalangan tosh avvaldan umumiy asfaltbetonning taxminan 1 % qismi bilan qoplangan bo‘lishi kerak. Shuningdek, oldindan qoplangan tosh ishlab chiqarishda tosh to‘ldirgich (filler) miqdori asfaltbeton miqdoriga teng bo‘lishi kerak.

Quyma asfaltbeton bog‘lovchi qatlamga (binder course) qo‘llanilganda, yuza qatlami bilan moslashuvni yaxshilash va plastik oqimga (deformatsiyaga) chidamlilikni oshirish uchun ba’zan 13,2 dan 4,75 mm gacha va 19 dan 13,2 mm gacha bo‘lgan chaqiqtoshlar ishlatiladi[6].

Qoplama yuzasiga bosib kiritilmagan (yopishmagan) barcha toshlar transport harakati ochilishidan yoki yuzani qoplashdan oldin supirib tashlanishi kerak.

3. Xulosa

Quyma asfaltbeton uni boshqa ko‘plab asfaltbeton turlaridan ajratib turadigan bir qator afzalliklarga ega. Biroq, bizning mamlakatimizda u yuqori narxi tufayli yo‘l qurilishi uchun asosiy material emas. Biroq, olib borilgan tadqiqotlar uning xususiyatlari uning yuqori narxini qoplashini isbatlaydi. Quyma asfaltbetonning ko‘plab afzalliklarini sanab o‘tish mumkin ulardan ba’zilari zichlashni talab qilmaydi, korroziya va deformatsiyaga yuqori qarshilik, materialning ta’sirchan mustahkamligi va qattiqligi, zichlikning odatdagidan oshishi, yuqori namlikka chidamlilik, uzoq xizmat muddati, qoplama silliq va bir tekis bo‘lishi shular jumlasidandir.

Quyma asfaltbetonning ayrim kamchiliklari: narxining odatdagidan birmuncha qimmatligi, materialni yetkazib berish va o‘rnatish uchun maxsus uskunalarga ehtiyoj borligi, laboratoriyada kompozitsiyani tanlashning sifatsizligi yoki modifikatsiyalanmagan bitumlardan foydalanilganda yorilishlar kuzatilishi mumkinligi deb qayd etilgan.

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Analysis of energy losses in photovoltaic power plants under the climatic conditions of Karshi

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Abstract: This scientific article presents a comprehensive analysis of energy losses in photovoltaic power plants under the climatic conditions of Karshi. The study identifies and systematizes the main factors affecting the conversion of solar energy into electrical energy, including shading, soiling, temperature effects, module degradation, and electrical losses, along with their quantitative assessment. Considering the high solar radiation and sharply continental climate of the region, scientifically grounded recommendations for improving the efficiency of photovoltaic systems have been developed.

Keywords: photovoltaic power plant, solar energy, energy losses, Karshi climate, efficiency, solar radiation, efficiency coefficient, shading, degradation

1. Introduction

The increasing global energy demand, depletion of fossil fuels, and environmental concerns have accelerated the transition toward renewable energy sources. Among them, solar energy is one of the most promising due to its availability, sustainability, and environmental benefits. Photovoltaic (PV) systems, which directly convert solar radiation into electricity, play a key role in modern energy production. In agricultural regions, energy costs represent about 30–35% of total production expenses, making energy efficiency and renewable integration essential for sustainable development. Decentralized PV systems are therefore widely implemented in rural areas with high solar potential. The Karshi region of Uzbekistan is characterized by high solar irradiation (1500–1700 kWh/m² per year), making it suitable for PV deployment. However, the actual performance of PV systems is often lower than theoretical expectations due to various energy losses, including shading, dust accumulation, temperature effects, module degradation, and electrical losses. Despite numerous studies on PV performance, limited research has focused on Central Asian climatic conditions, particularly Uzbekistan. Therefore, a region-specific analysis is required. This study aims to analyze and classify the main energy loss factors in PV systems under Karshi climatic conditions and to propose methods for improving system efficiency. The novelty of this work lies in adapting PV loss analysis to local environmental factors, especially high temperature and dust impact, which are insufficiently addressed in previous research.

2. Research methodology

This study applies a combined analytical and modeling approach to evaluate energy losses in photovoltaic (PV) power plants under the climatic conditions of the Karshi region. The methodology integrates theoretical analysis, empirical interpretation, and mathematical estimation to ensure result reliability. The study area is the Karshi region in southern Uzbekistan (38°52′ N, 65°48′ E), characterized by a sharply continental climate with hot summers and mild winters. Annual solar irradiation ranges from 1500 to 1700 kWh/m², making the region highly suitable for PV applications. However, environmental conditions such as high ambient temperatures (up to +45°C), dust accumulation, low humidity, and seasonal winds significantly affect system performance and increase energy losses [1]. A standard grid-connected PV system was considered, consisting of monocrystalline PV modules, DC cabling, an inverter unit, AC transmission lines, and an optional transformer. The selected PV modules (200–400 W, 15–20% efficiency, 24–40 V, monocrystalline silicon technology) represent widely used commercial systems, ensuring practical relevance of the results [2]. Energy losses were classified into two main categories:

Solar Energy Losses. These occur during the conversion of solar radiation into electrical energy and include:

- Shading losses (near and far shading effects)

Soiling losses due to dust and surface загрязнение

- Losses caused by non-optimal tilt and orientation
- Thermal losses due to elevated operating temperatures
- Module degradation over time
- Mismatch losses between PV modules

Electrical Losses. These losses occur during energy transmission and conversion processes: Cable (ohmic) losses in DC and AC circuits, Inverter conversion losses, Transformer losses, Losses due to improper system configuration. Calculation and Estimation Methods: The estimation of energy losses was carried out using standard analytical expressions and empirical coefficients derived from literature sources. The total energy output of a photovoltaic system can be expressed as:

$$E_{out} = E_{in} \cdot \eta_{pv} \cdot (1 - L_{Total})$$

where: E_{out} – electrical energy output, E_{in} – incident solar energy, η_{pv} – module efficiency, L_{Total} – total energy loss factor. [3]

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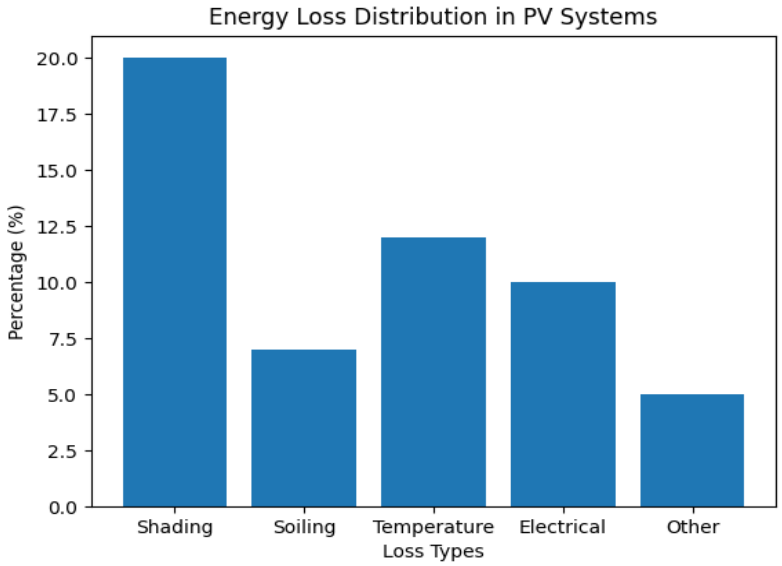

Fig. 1. Energy loss distribution in PV systems

The chart illustrates that shading and temperature are dominant loss factors in Karshi conditions.

The total loss factor is calculated as the sum of individual losses:

$$L_{Total} = L_{sh} + L_{so} + L_{temp} + L_{deg} + L_{el}$$

where: L_{sh} – shading losses, L_{so} – soiling losses, L_{temp} – temperature losses,

L_{deg}– degradation losses, L_{el}– electrical losses.

Temperature impact on PV efficiency was evaluated using the temperature coefficient model:

$$\eta\,(T) = \eta_{ref}\,[1 - \beta\,(T - T_{ref}\,)]$$

where: β – temperature coefficient, T– operating temperature, T_{ref} – reference temperature (25°C).

Data Sources and Analysis Tools

The study utilizes: published scientific literature, operational data from existing photovoltaic systems, regional climatic statistics.

Comparative analysis and systematization methods were applied to identify dominant loss factors and quantify their impact under Karshi conditions.

This study employs an integrated methodological framework combining analytical modeling, empirical monitoring data, and energy balance analysis to evaluate energy losses in photovoltaic (PV) systems under the climatic conditions of the Karshi region.

Study Object and Site Description

The research object is a 370 kW grid-connected photovoltaic power plant installed at Karshi State University, Pedagogical Faculty. The system operates under real load conditions and is used both for electricity supply and experimental analysis.

The study area is located in the Karshi region (38°52′ N, 65°48′ E), characterized by:

High solar irradiation (1500–1700 kWh/m²/year)

High ambient temperature (up to +45°C)

Dust-prone semi-arid environment

Seasonal wind and low humidity

These conditions create favorable solar potential but also introduce significant performance losses.

Data Collection and Monitoring

Table 9

Day Operational Performance of the Photovoltaic Power Plant

Date	Energy Generated by PV, kWh	Energy Consumed, kWh	Energy Exported to Grid, kWh	Energy Imported from Grid, kWh
2025-12-14	73.53	0.87	73.00	0.34
2025-12-15	273.11	0.34	273.50	0.00
2025-12-17	36.74	0.89	36.06	0.21
2025-12-18	31.84	0.00	0.00	0.00
2025-12-20	12.25	1.09	11.56	0.40
2025-12-21	93.24	1.09	92.75	0.60
2025-12-22	360.60	0.00	361.25	0.59
2025-12-23	370.80	0.05	371.38	0.63
2025-12-24	89.81	0.15	90.00	0.34

The study is based on real operational data collected over a 9–10 day monitoring period (December 2025) . The operational performance of the photovoltaic power plant was evaluated using a 9-day dataset collected in December 2025.

The monitored parameters included the energy generated by the PV system, local energy consumption, energy exported to the grid, and energy imported from the grid. The summarized results are presented in Table [12].

The following parameters were recorded daily:

- E_{PV} – energy generated by the PV system (kWh)
- E_{cons}– energy consumed locally (kWh)
- E_{grid} - energy exported to the grid (kWh)
- $E_{imported}$– energy imported from the grid (kWh)

These data were obtained from the system's monitoring platform and processed using statistical analysis methods.

Energy Balance Method

The performance of the photovoltaic system was evaluated using the energy balance approach, which allows quantifying system losses under real operating conditions:

$$E_{PV} = E_{cons} + E_{grid} + E_{loss}$$

where:

- E_{loss} – total system energy losses

From this, total losses are determined as:

$$E_{loss} = E_{PV} - (E_{cons} + E_{grid})$$

The system efficiency is calculated as:

$$\eta = \frac{E_{cons} + E_{grid}}{E_{PV}} \times 100\%$$

This method provides a realistic evaluation of system performance and is widely used in PV monitoring standards (IEC 61724).

Analytical Loss Modeling

In addition to empirical analysis, energy losses were evaluated using analytical modeling:

$$E_{out} = E_{solar} \cdot \eta_{pv} .(1 - L_{totol})$$

Total loss factor is defined as:

$$L_{totol} = L_{sh} + L_{so} + L_{temp} + L_{deg} + L_{el} + L_{miss}$$

where individual losses represent:

- L_{sh} – shading losses
- L_{so} – soiling (dust) losses
- L_{temp} – temperature losses
- L_{deg} – degradation losses
- L_{el} – electrical losses
- L_{miss}– mismatch losses

Temperature Impact Assessment

Temperature influence was evaluated using the standard model:

$$\eta = \eta_{ref}\,[1 - \beta(T - 25)]$$

Additionally, module temperature was estimated as:

$$T_{module} = T_{ambient} + \frac{NOCT - 20}{800} \cdot G$$

This allows accurate estimation of thermal losses under Karshi climatic conditions. The collected operational data were analyzed using a combination of statistical and comparative methods to ensure a comprehensive evaluation of the photovoltaic system performance. The analysis included a comparative assessment of daily energy production values over the monitoring period, as well as an evaluation of the relationship between solar radiation intensity and energy output. In addition, high and low production days were identified and classified in order to better understand the variability of system performance under changing environmental conditions. The measured performance indicators were also compared with theoretical expectations to assess the consistency between real and modeled results. Particular attention was given to peak production days, such as December 22–23, during which the system operated close to its nominal capacity, demonstrating optimal performance under favorable solar radiation conditions.

To ensure the reliability and accuracy of the obtained results, several validation approaches were applied. Empirical data were cross-checked against analytical calculations based on standard photovoltaic performance models. Furthermore, the estimated loss values were compared with ranges reported in scientific literature, and the results were validated in accordance with internationally recognized photovoltaic system monitoring standards, including IEC 61724. These steps ensured the consistency, reliability, and scientific credibility of the analysis. The proposed methodology provides several important contributions. It integrates real operational monitoring data with analytical modeling approaches, allowing for a more accurate and practical assessment of photovoltaic system performance. The application of the energy balance method under specific local climatic conditions enhances the relevance of the results, particularly for regions characterized by high temperatures and dusty environments such as Karshi. In addition, the methodology has practical applicability for evaluating and optimizing photovoltaic systems in educational and institutional settings, making it a valuable tool for both scientific research and applied engineering practice.

3. Results and Discussion

The analysis of the photovoltaic power plant performance was carried out using real operational data collected over a 9-day period in December 2025. The results demonstrate that the system operates with high efficiency under real conditions. The total energy generated during the observation period amounted to 1341.92 kWh, while the useful energy (consumed locally and exported to the grid) reached approximately 1343.98 kWh. The calculated difference between generated and utilized energy is negligible (approximately 0.15%), indicating minimal system losses. In several cases, the calculated efficiency exceeded 100%, which can be attributed to measurement uncertainties, inverter data processing characteristics, and rounding errors in monitoring systems. Such deviations are commonly observed in real photovoltaic system measurements and do not indicate physical inconsistencies. A notable observation is the significant variation in daily energy production. On high solar radiation days (December 22–23), the system generated up to 360–370 kWh, operating close to its nominal capacity. In contrast, during low radiation conditions (e.g., December 20), production dropped to as low as 12.25 kWh, confirming the strong dependence of PV systems on solar irradiance.

The results also indicate that the majority of generated energy is effectively utilized or exported to the grid, with very low internal consumption. This suggests that electrical losses (cable, inverter, transformer) are minimal and the system is well-optimized. Overall, the findings confirm that under proper design and operation, photovoltaic systems can achieve near-ideal performance, especially in regions with high solar potential such as Karshi. However, fluctuations in solar radiation remain the dominant factor affecting energy production.The results of this study indicate that energy losses in photovoltaic (PV) systems under the climatic conditions of the Karshi region are considerable, ranging from 25% to 50% of the theoretical energy potential. These losses depend on system design, installation quality, and maintenance practices. Among environmental factors, dust and sand accumulation (soiling) represent a major source of performance degradation due to the semi-arid climate and frequent wind activity. Soiling losses are estimated at 3–7%,

and may exceed this range under extreme conditions. Shading effects also significantly reduce system efficiency. Improper spacing between PV arrays leads to near and far shading, particularly during low solar elevation periods. Estimated losses include 5–20% for near shading and 2–10% for far shading. Combined shading effects further reduce the effective irradiance on PV modules [4,5]. System design parameters, particularly tilt angle and azimuth orientation, strongly influence energy yield. The optimal tilt angle for the Karshi region is approximately 30–35° facing south. Deviations from optimal configuration may cause 10–20% losses due to tilt mismatch, while incorrect azimuth orientation can reduce output by an additional 5–10% [6]. Temperature effects represent another critical loss factor. High ambient temperatures exceeding +40°C during summer reduce PV efficiency by decreasing the open-circuit voltage of the modules, leading to a noticeable decline in power output.

The temperature-related efficiency drop can be described as:

$$\eta\,(T) = \eta_{ref}\,[1 - \beta\,(T - T_{ref}\,)]$$

Temperature-related losses in the Karshi region are estimated to range between 5% and 12%, depending on module technology, thermal characteristics, and cooling conditions [7]. These losses are primarily caused by the reduction in open-circuit voltage as module temperature increases. Long-term performance degradation also contributes to energy losses. In the studied climatic conditions, annual degradation rates are estimated at 0.5–1%, leading to cumulative efficiency reduction over the system lifetime. In addition, mismatch losses caused by non-uniform module performance and uneven soiling contribute approximately 1–3% additional losses, which are often underestimated in system design. Electrical losses occur during energy conversion and transmission stages and include cable, inverter, and transformer losses. Cable losses account for 2–5% due to resistive heating, inverter losses range between 2–4% depending on conversion efficiency, and transformer losses contribute an additional 2–5% including no-load and load conditions. Although individually moderate, these losses collectively have a significant impact on overall system efficiency, particularly in sub-optimally designed installations. The total energy output of the photovoltaic system can be expressed using the following general relationship:

$$E_{out} = E_{in} \cdot \eta_{pv} \cdot (1 - L_{total})$$

For the Karshi region, the annual solar irradiation is approximately 1600 kWh/m², while the effective electrical output ranges between 900 and 1100 kWh/m². This corresponds to total system losses of about 30–40% under typical operating conditions [8]. The comparative analysis shows that solar-related losses significantly dominate over electrical losses in the studied region. The most influential factors affecting system performance include dust accumulation (soiling), high ambient temperature, and improper tilt and orientation of PV modules. In poorly optimized systems, total losses may exceed 50%, resulting in a drastic reduction of efficiency to as low as 5–10%. In contrast, well-designed and properly maintained photovoltaic systems can achieve efficiencies in the range of 12–15% under local climatic conditions [9]. To enhance system performance, several mitigation strategies are recommended, including regular cleaning of PV modules to reduce soiling losses, optimization of tilt angle and azimuth orientation during installation, application of passive or active cooling techniques, use of high-efficiency inverters and appropriately sized cables, and minimization of shading through proper system layout design. Overall, the findings confirm that although the Karshi region possesses high solar energy potential, the actual performance of photovoltaic systems is strongly influenced by environmental and technical factors. Proper system design, installation, and maintenance are essential to minimize energy losses and maximize energy yieldof structural material (NMQ_i) is calculated as the weight of material per unit area of the bridge deck:

$$NMQ_i\,[kg/m^2] = \frac{SMQi[kg]}{Length\,[m] \times Width[m]}$$

3. Calculating Embodied Carbon (EC)

The embodied carbon of each structural material is calculated by multiplying the normalized material quantity by its embodied carbon coefficient:

$$EC_i\,[kgCO_2e/m^2] = NMQ_i\,[kg/m^2] \times ECC_i[kgCO_2e/kg]$$

4. Global Warming Potential of the Bridge (GWP)

Finally, the total embodied carbon or global warming potential of the bridge is calculated as the sum of the embodied carbon of all materials:

$$GWP[kgCO_2e/m^2] = \Sigma EC_i\,[kgCO_2e/m^2]$$

This methodology provides a structured framework for evaluating the environmental impact of bridges during their construction stage and allows comparison across different bridge types.

4. Conclusion

This study provides a comprehensive analysis of energy losses in photovoltaic (PV) power plants under the climatic conditions of the Karshi region. Despite high solar irradiation potential (1500–1700 kWh/m² per year), the actual performance of PV systems is significantly reduced due to multiple environmental and technical loss factors. The results show that total energy losses range between 25% and 50%, depending on system design, environmental conditions, and operational practices. The dominant losses are associated with solar-related factors, particularly dust accumulation, shading effects, improper tilt angle, and high ambient temperature. Among these, soiling and thermal effects are the most critical due to the arid climate and extreme summer conditions in the Karshi region. Electrical losses in cables, inverters, and transformers contribute a smaller but still significant portion of total system inefficiency, especially in poorly designed installations. The study confirms that system efficiency may decrease to 5–10% under suboptimal conditions, whereas properly designed and maintained systems can achieve efficiencies of 12–15%.

To improve PV system performance, several measures are recommended, including optimization of tilt angle and orientation based on local solar geometry, regular cleaning of PV modules, implementation of cooling strategies, proper system layout to minimize shading and mismatch losses, and the use of high-efficiency electrical components. In conclusion, although the Karshi region has strong potential for solar energy utilization, achieving high photovoltaic efficiency requires an integrated approach combining climatic adaptation, engineering optimization, and effective maintenance. The findings of this study provide a useful basis for the design and improvement of PV systems in similar arid and high-temperature regions.

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Women's role in engineering innovation and scientific leadership in modern stem systems

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Abstract: This scientific article presents a comprehensive analysis of energy losses in photovoltaic power plants under the climatic conditions of Karshi. The study identifies and systematizes the main factors affecting the conversion of solar energy into electrical energy, including shading, soiling, temperature effects, module degradation, and electrical losses, along with their quantitative assessment. Considering the high solar radiation and sharply continental climate of the region, scientifically grounded recommendations for improving the efficiency of photovoltaic systems have been developed.

Keywords: women in STEM, engineering innovation, gender equality, scientific leadership, technology development, STEM education

1. Introduction

The twenty-first century has witnessed unprecedented technological transformation driven by rapid advancements in science, engineering, and digital innovation. Engineering disciplines play a crucial role in addressing complex global challenges such as climate change, sustainable energy systems, digital transformation, and industrial modernization. However, despite progress in educational access and workforce participation, women remain significantly underrepresented in many STEM disciplines, particularly in engineering and technology sectors [1].

This imbalance presents not only a gender equality issue but also a challenge for scientific progress itself. Diverse research teams tend to demonstrate higher levels of creativity, problem-solving capacity, and interdisciplinary collaboration. When women are underrepresented in engineering research and innovation processes, the scientific community loses valuable intellectual perspectives that could contribute to technological advancement and societal development.

In recent years, governments, universities, and international organizations have increasingly recognized the importance of promoting women's participation in STEM. Numerous initiatives—including scholarship programs, mentorship networks, and leadership development platforms—have been established to encourage women to pursue careers in engineering and scientific research [2]. These programs aim to reduce structural barriers and improve women's access to professional opportunities within academic and industrial research environments.

Historically, women have contributed significantly to scientific and engineering achievements, although their contributions have often been underrecognized. Improvements in higher education access, international collaboration, and research infrastructure have gradually increased women's representation in engineering and technology programs worldwide. According to international statistical reports, the number of women entering engineering and technological fields has steadily increased over the past two decades, reflecting the influence of inclusive educational policies and global gender equality initiatives [3].

The growing presence of women engineers and scientists contributes to strengthening research communities by introducing diverse perspectives and encouraging interdisciplinary approaches to innovation. Research suggests that heterogeneous teams are often more capable of generating creative technological solutions that address complex societal needs. Therefore, expanding women's participation in engineering research is not only a matter of social equality but also an important factor for improving scientific productivity and innovation capacity.

Despite this progress, women continue to face multiple structural challenges within engineering and STEM careers. These barriers include limited access to leadership positions, gender stereotypes in technical professions, unequal distribution of research funding, and restricted opportunities for professional advancement [4]. In many regions, cultural expectations and traditional social norms further discourage women from pursuing careers in engineering and technology, contributing to the persistence of gender disparities in STEM disciplines.

Another significant challenge is the lack of visible female role models within engineering leadership. When young women do not observe successful women scientists and engineers occupying influential academic or industrial positions, their motivation to pursue similar career paths may be reduced. Increasing the visibility of women leaders in scientific and technological fields is therefore essential for inspiring future generations of researchers and innovators.

To address these challenges effectively, universities, research institutions, and policy-making bodies must implement institutional strategies that actively support women's participation in engineering research and technological innovation. Mentorship programs, leadership training initiatives, and specialized research grants designed for women scientists can significantly enhance professional development and research productivity [5]. Furthermore, integrating gender equality principles into national innovation policies and scientific development strategies can foster more inclusive research ecosystems.

International collaboration also plays an important role in promoting women's contributions to science and engineering. Academic conferences, research networks, and global scientific forums provide valuable platforms where women researchers can present their work, establish professional partnerships, and increase their visibility within the international scientific community. Through these collaborative efforts, the participation and influence of women in engineering innovation can be substantially strengthened.

The objective of this study is to analyze the role of women in engineering innovation and scientific leadership within modern STEM systems, with particular attention to institutional mechanisms that promote gender equality and inclusive scientific development.

2. Research methodology

This study adopts a structured qualitative-analytical approach designed to provide a coherent and evidence-based examination of women's participation in engineering innovation and scientific leadership within contemporary STEM systems. The methodological framework is built on the integration of secondary data analysis, comparative evaluation, and conceptual interpretation in order to ensure analytical consistency and academic rigor. The research relies on statistical and institutional data obtained from internationally recognized organizations, including UNESCO, OECD, World Bank, and the National Science Foundation, which provide reliable indicators on gender distribution in engineering education, research activity, and leadership representation. The use of such sources is essential for maintaining comparability across regions and avoiding subjective or unverified assumptions.

A cross-country comparative perspective is applied to identify structural differences in women's participation across various economic and institutional contexts. This comparison focuses on key measurable dimensions, including access to engineering education, representation in research institutions, participation in innovation systems, and involvement in decision-making positions. Rather than treating these indicators independently, the study interprets them within an integrated analytical framework that combines gender equality theory with innovation system theory, allowing for a systematic understanding of how institutional structures and policy environments shape participation outcomes.

To strengthen the analytical depth, the study incorporates content analysis of academic literature, policy reports, and documented international practices. This enables the identification of recurring patterns related to barriers, institutional constraints, and enabling mechanisms such as mentorship programs, funding access, and leadership development initiatives. Particular attention is given to the interaction between formal institutional policies and underlying socio-cultural factors, recognizing that disparities in STEM participation are driven by both structural and contextual influences.

Finally, the study employs a qualitative correlation approach to assess the relationship between women's participation and innovation performance. Instead of relying on formal econometric modeling, the analysis systematically synthesizes empirical evidence and theoretical insights to establish logically consistent connections between gender diversity, research productivity, and innovation outcomes. This methodological choice prioritizes clarity of interpretation and conceptual validity, ensuring that the conclusions are grounded in observable trends rather than unsupported generalizations.

3. Results and Discussion

The analysis demonstrates that increasing women's participation in engineering and STEM fields is directly associated with stronger innovation performance and more effective research systems. While global data indicate a steady rise in female enrollment in engineering education, this progress does not extend proportionally to leadership positions or advanced research roles. This imbalance reflects a structural limitation within STEM systems, where participation at entry levels does not translate into sustained career advancement, resulting in a gradual reduction of female representation at higher levels of responsibility.

Institutional analysis shows that organizations with greater gender diversity tend to achieve higher levels of research productivity and innovation efficiency. This outcome is linked to the presence of varied perspectives within research teams, which enhances problem-solving capacity and supports the development of interdisciplinary solutions. In environments characterized by complex technological challenges, such diversity becomes a functional advantage rather than a normative objective.

The findings also indicate that targeted institutional and policy interventions contribute positively to improving women's participation. Programs focused on education access, professional development, and leadership support have demonstrated measurable impact, particularly in systems where these initiatives are implemented consistently. However, the effectiveness of such measures is constrained in contexts where socio-cultural factors continue to influence career pathways. Persistent stereotypes and traditional role expectations remain significant barriers, limiting the long-term retention and advancement of women in engineering fields.

Another important observation concerns the role of women in leadership positions. Institutions that include women in strategic decision-making processes tend to demonstrate more balanced and socially responsive approaches to innovation. This suggests that participation at the leadership level influences not only representation but also the direction and quality of technological development.

Overall, the results confirm that gender inclusion in STEM is closely linked to the functional capacity of innovation systems. Expanding women's participation contributes to more adaptive, efficient, and resilient research environments. Conversely, underutilization of this potential represents a structural inefficiency that directly limits scientific and technological progress.

4. Conclusion

The analysis presented in this study demonstrates that women's participation in engineering and technological innovation represents a critical factor for strengthening contemporary scientific ecosystems. Increased representation of women in STEM contributes to greater diversity of perspectives, which enhances creativity, interdisciplinary collaboration, and the development of socially relevant technological solutions.

Although significant progress has been achieved in expanding women's access to STEM education and research opportunities, disparities remain evident in leadership positions, research funding distribution, and representation within engineering industries. Addressing these gaps requires coordinated efforts at institutional, national, and international levels.

Policies aimed at ensuring equitable access to education, research resources, and leadership opportunities can significantly strengthen women's engagement in engineering innovation. In addition, mentorship programs, professional

networks, and international scientific collaborations play an important role in supporting the professional development and global visibility of women researchers.

Ultimately, strengthening women's participation in STEM fields is not only a matter of social justice but also a strategic necessity for building inclusive, innovative, and sustainable scientific systems capable of addressing complex global challenges.

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Problems of preservation, reconstruction and restoration of the historical and cultural heritage of Bukhara

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Abstract: The article is devoted to the analysis of the issues of preservation, reconstruction and restoration of the historical and cultural heritage of Bukhara. The historical experience of monument care from ancient times to the Soviet period is considered, achievements and mistakes in the field of restoration in the 20th century are assessed. Particular attention is paid to modern projects implemented with the support of international organizations, as well as current challenges associated with preserving the authenticity of the architectural appearance of the city. The author emphasizes the need for an integrated approach that combines scientific methods, traditional techniques and modern technologies for the effective protection of the cultural heritage of Bukhara.

Also, modern problems of preservation, reconstruction and restoration of the historical and cultural heritage of the city of Bukhara - one of the most important centers of Islamic architecture in Central Asia are considered. Based on the analysis of historical sources, architectural monuments and restoration practices of the 20th-21st centuries, both successful examples of preservation and mistakes leading to the loss of authenticity are identified. Particular attention is paid to the methods and materials used in the restoration of key sites, such as the Lyabi-Khauz and Poi-Kalyan ensembles. The necessity of a comprehensive and scientifically based approach to the protection of cultural heritage in the context of modern urbanization and tourism is emphasized.

Keywords: Bukhara, historical and cultural heritage, restoration, reconstruction, preservation of monuments, UNESCO, architecture, traditional methods, modern restoration. architecture of Central Asia; Lyabi-Khauz; Kalyan minaret

1. Introduction

Bukhara is one of the oldest cities in Central Asia, with a rich history and unique cultural heritage. Since the 10th century, it has been a center of Islamic science and art, and during the era of the Bukhara Emirate it became an important political and cultural hub in the region [1]. Bukhara's monuments are not only architectural structures, but also evidence of the philosophical, literary and scientific life that formed a unique civilization[2].

Preserving this heritage is a complex task that involves studying the history of restoration methods, understanding the mistakes of the past and developing modern approaches that meet international standards [3].

In the traditional society of Bukhara, the care of architectural monuments was carried out within the framework of religious and social initiatives. The maintenance of mosques, madrassas and mausoleums was often financed through waqfs (charitable donations), which allowed them to be maintained in satisfactory condition [4]. Local master restorers ("usto") used traditional building materials and methods, ensuring the continuity of architectural techniques. The history of Bukhara knows many catastrophic events: the Mongol invasion of the 13th century, internal wars, natural disasters[5,7]. Each time, the restoration was carried out taking into account traditional architectural principles. Particularly intensive work was carried out during the reign of the Timurids and Sheibanids, when Bukhara turned into one of the religious centers of the Muslim world[6]. The famous historian Narshakhi wrote in one of his books, "The History of Bukhara," that the city was called "Numizhkat" (or "Bumis kat").[] He also mentioned that in Arabic the city had two names: Madinat al-Sufriyya (the copper city) and "Madinat al-Tijjar" (the city of merchants) [8]. It was also mentioned there that in Khorasan there was not a single similar city that would be given as many names as Bukhara was called. Historical monuments, which are masterpieces of architecture, have attracted tourists and pilgrims from all over the world for centuries. Most of the city has remained untouched and represents a living history that has reached our time. Along with the old part with numerous architectural monuments, the city is a modern industrial and cultural center. Academician V.V. Bartold associated the origin of the city's name with the Sanskrit "vihara" - a Buddhist monastery [10,11].

In 1993, the historical part of Bukhara was included by UNESCO in the list of cities of world heritage of humanity. In 1997, under the auspices of UNESCO, the 2500th anniversary of the city was widely celebrated on an international scale [12].

The era of the Bukhara Emirate. In the 18th-19th centuries, a new rise in urban development is observed: madrassas (for example, the Miri Arab madrassah), mosques, bazaars are being restored [13]. At the same time, interest in the preservation of old monuments is increasing, which is confirmed by numerous records of restoration work recorded in documents. With the establishment of Soviet power at the beginning of the 20th century, the attitude

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towards the monuments of Bukhara changed. On the one hand, large-scale research and the creation of protective lists of architectural monuments began. In the 1920s and 1930s, the first scientific restoration work was undertaken, organized by the Monument Protection Committee. Among the successful projects was the restoration of the Lyabi-Khauz ensemble [14].

However, the ideological attitudes of the era also led to destruction: mosques and madrassas were used for warehouses, barracks, and workshops. Sometimes, during restoration, the authenticity of the buildings was violated: unusual architectural elements were added or work was carried out without due consideration of historical features [15].

By the beginning of the 1990s, many monuments of Bukhara were in critical condition. Some structures, such as mosques and madrassas, required urgent conservation and restoration measures. Spontaneous construction around the historical center led to the loss of the integrity of the ancient urban landscape. Preservation of the historical and cultural heritage of Bukhara requires the comprehensive application of both traditional and modern scientifically based approaches. Restoration activities are carried out taking into account the authenticity of architectural forms, the stability of structures and the cultural significance of the object. The methods and materials used are determined by the type of monument, the degree of its destruction and historical and artistic value [16].

The architectural ensembles of Poi-Kalyan, Lyabi-Khauz, Gaukushon, Bahauddin Naqshband, Chor-Bakr, Toshmachit, the Samanid Mausoleum and others are the best examples of the works of medieval architects of the 11th-17th centuries. The uniqueness of the cultural heritage of Bukhara is determined by the centuries-long stable (almost uninterrupted) development of a significant city on a single territory, without the transfer of construction to new sites typical of Islamic cities. This allowed the formation of a surprisingly organic, densely saturated "fabric" of urban development, including, along with the narrow streets and "sea" of residential buildings with inner courtyards typical of Eastern cities, many outstanding architectural monuments - not only individual ones, but also entire ensembles and complexes. The centuries-old activity of thinkers, architects, poets earned the city the honorary titles of "Dome of Faith", "Noble Bukhara", "Blessed City".

2. Research methodology

Restoration and reconstruction work on the territory of historical Bukhara is based on a comprehensive interdisciplinary approach, including methods of architectural analysis, archaeological research, source studies and engineering survey. The main goal is to preserve the cultural and artistic value of the object with minimal interference in its historical substance.

The methodological basis of this study is based on a comprehensive approach, including historical and architectural analysis, source study method, comparative typological approach, as well as elements of applied technical disciplines used in the field of restoration and reconstruction of architectural monuments.

The purpose of the study is to identify and systematize the methods and materials used in the restoration and reconstruction of the historical and cultural heritage of the city of Bukhara, as well as an analysis of the effectiveness of their use from the standpoint of preserving the authenticity of the objects. It is carried out on the basis of studying archival materials, chronicles (in particular, "Tarikh-i Bukhara"), waqf documents, reports of restoration expeditions and visual sources (photographs, drawings of the 19th-20th centuries). This method allows us to determine the original appearance of monuments and record the stages of their transformation.

It is used to identify the stratigraphy of building layers, determine the technology of masonry and building materials. This approach was especially important in studying such objects as the Ismail Samani Mausoleum, the Kalyan ensemble and the Miri-Arab Madrasah. It is used to compare various historical buildings with their analogues inside Bukhara and other cities of Central Asia (Samarkand, Khiva), which allows us to identify the characteristic elements of the Bukhara architectural school.

Include geodetic survey, 3D scanning, photogrammetry and inspection of structures using modern technical means. These methods provide an accurate recording of the current state of monuments and allow us to model possible restoration solutions. It involves studying the composition of building solutions, the structure and origin of bricks, tiles, plasters. It also considers the use of modern polymer and strengthening compounds, as well as engineering solutions in the restoration of structures. Results and discussion. In 1993, the historic center of Bukhara was included in the UNESCO World Heritage List. This event gave impetus to the implementation of large international restoration programs. One of the landmark projects was the restoration of the Poi-Kalyan ensemble (Kalyan minaret, Kalyan mosque, Miri Arab madrasah), where the latest conservation methods were used: 3D scanning of the surface, microanalysis of materials, strengthening of the foundation using modern technologies.

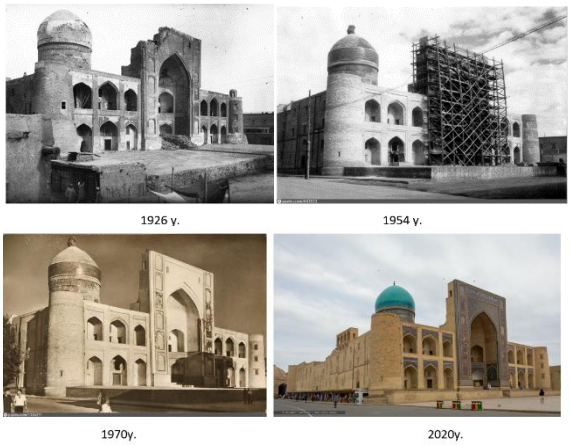

Fig. 1. Miri-Arab Madrasah, Bukhara

Restoration and improvement work was also carried out on the Lyabi-Khauz ensemble, the Ulugbek madrasah, and the Ismail Samani mausoleum. The Lyabi-Khauz ensemble, formed in the 17th century, is one of the key architectural complexes in the historical center of Bukhara, included in the UNESCO World Heritage List. The complex unites three main monuments: the Kukeldash madrasah (1568–1569), the khanaka and the Nadir Divanbegi madrasah (1620–

1622), located around an artificial reservoir, the hauz. The first restoration work on the Lyabi-Khauz ensemble was carried out in the 1950s and 1960s as part of the state program for the preservation of architectural monuments of the Uzbek SSR. The main goal was to eliminate hazardous areas, clear the territory of late buildings, and strengthen the foundations of the structures. In the second half of the 20th century, specialists from the Institute of Architecture of Uzbekistan participated in restoration work, in particular under the supervision of restorer Sh. Bulatov and architect G. A. Pugachev. During this period, the following was done:

- measurements of buildings and detailed photo recording were carried out;
- destroyed parts of the portals of the khanaka and madrasah were restored;
- lost sections of majolica and carved panels were reconstructed;
- the vaults and cornices of the Kukeldash madrasah were strengthened.

The restoration work of the Lyabi-Khauz ensemble demonstrated the need for a balance between:

- preserving historical authenticity and
- adapting objects to modern tourist use.

Mostly traditional materials were used (fired brick, majolica, lime mortars), but modern technologies (reinforcement, waterproofing of foundations) were used in hidden structures. The Lyabi-Khauz ensemble is not only an architectural dominant of old Bukhara, but also functions as a public space. Thanks to the restoration, the complex was returned to active cultural life, while preserving its historical and artistic value. It has become a model example of a successful combination of scientific restoration, tourist infrastructure and urban improvement.

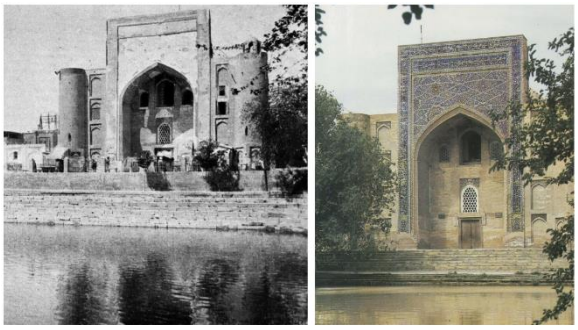

Fig. 2. 1923 Lyabi-Khauz, Divanbegi khanaka
1982 Lyabi-Khauz, Divanbegi khanaka

The Kalyan Minaret, built in 1127 by order of the Karakhanid ruler Arslan Khan, is an outstanding example of the architecture of the Islamic East. With a height of about 46.5 meters and unique brickwork, it became not only a religious building, but also an important urban landmark of old Bukhara. Its architectural harmony and stability ensured the durability of the structure, but over the centuries it was subjected to the destructive effects of time, nature and man.

Initial attempts to describe the condition of the minaret were made by Russian orientalists and architects as part of Turkestan archaeological expeditions. Even then, partial damage to the masonry and the destruction of decorative friezes were noted.

Restoration work began in the 1930s and intensified in the 1950s–1970s as part of a large-scale program to preserve monuments of Central Asia. Under the supervision of the architect-restorer Sh. Bulatov the following was completed:

- minaret measurements and crack fixation;
- injection cementation of the base to strengthen the foundation;
- replacement and partial re-laying of destroyed sections of brickwork;
- clearing and restoration of belt ornaments;
- conservation of the upper tier (guldasta) using majolica and brick identical to the original.

A large-scale project for the comprehensive restoration of the Poi-Kalyan ensemble, which includes the minaret, was implemented for the 2500th anniversary of Bukhara (1997). The main works included: engineering survey of the foundation condition using ground penetrating radars; base leveling by reinforcing with cement-sand mortars; cleaning the masonry from biological deposits; spot restoration of destroyed ornamental elements using the element-by-element replacement method; improvement of the adjacent territory: paving the area, organizing lighting, installing security barriers.

Fig. 3. 3 eras. Kalyan Minaret in Bukhara. 1907-1920-2017

Traditional materials were used in the restoration: hand-molded fired bricks, as close as possible in composition to medieval ones; lime and clay mortars; majolica for decorative fragments, made in Bukhara workshops.

Modern technologies were used covertly: injection strengthening compounds, reinforcement of the base, as well as waterproofing of the underground part. Restoration activities not only ensured the physical stability of the structure, but also contributed to its integration into the tourist and cultural environment of the city. The Kalyan Minaret has become a symbol of Bukhara, recognizable at the international level, as well as an object demonstrating an effective synthesis of traditional crafts and modern engineering approaches in the field of monument protection.

Today, new programs for the integrated preservation of heritage are being implemented in Bukhara, which include:

- Training of personnel in the field of restoration and museum affairs.
- Development of scientific research on the history of Bukhara architecture.
- Involvement of digital modeling technologies for monitoring the condition of monuments.
- Strengthening the legal protection of historical zones.

3. Conclusion

The historical and cultural heritage of Bukhara is a living testimony to many eras and civilizations. Past experience shows that successful preservation of monuments is possible only with a combination of respect for traditions, a scientific

approach and modern technologies. In the context of globalization, urbanization and the growth of tourism, the task of preserving the authentic appearance of ancient Bukhara is becoming especially urgent. Responsibility for the future of the city lies with both specialists and the general public, for whom Bukhara is not just a tourist attraction, but a part of the world's cultural memory. The analysis shows that despite the significant efforts made in the 20th-21st centuries, the processes of preservation, reconstruction and restoration of historical sites face a number of serious problems. These include: inconsistency between modern engineering solutions and traditional construction technologies; lack of qualified specialists in the field of scientific restoration; destructive influence of natural factors and urbanization pressure; non-compliance with international standards in a number of restoration projects; commercialization and tourist pressure, leading to the loss of the authenticity of the historical environment. The future of historical Bukhara directly depends on a conscious attitude towards its cultural heritage. Only in the conditions of a scientifically grounded, ethically balanced and legally regulated approach is it possible to ensure the preservation of this unique civilizational phenomenon for future generations.

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The 15-minute city as a framework for sustainable urban development: A comparative analysis of proximity-based planning in Paris, Vienna, and Tashkent

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Abstract: The 15-minute city has emerged as a contemporary urban planning paradigm aimed at improving sustainability, social equity, and quality of life by ensuring that essential daily services are accessible within a short walking or cycling distance from residential areas. By prioritizing proximity, mixed land use, and active mobility, the model challenges car-dependent urban development patterns and promotes human-centered urban environments. This paper examines the theoretical foundations of the 15-minute city concept, its implications for urban mobility and governance, and its applicability across diverse urban contexts, including transitional cities. Using a qualitative and comparative analytical approach, the study reviews international implementation practices and policy frameworks in order to identify both the opportunities and limitations of proximity-based planning. The findings indicate that the 15-minute city represents a flexible and adaptive framework for sustainable urban development; however, its successful implementation depends on integrated transport systems, inclusive planning policies, and context-sensitive adaptation to local socio-spatial conditions.

Keywords: 15-minute city, sustainable urbanism, proximity planning, walkability, urban mobility, inclusive development

1. Introduction

Rapid urbanization and motorization have significantly reshaped contemporary cities, often resulting in traffic congestion, environmental degradation, and socio-spatial inequality. Throughout the twentieth century, car-oriented planning paradigms prioritized speed and vehicular mobility, frequently at the expense of accessibility, public health, and urban livability. As a consequence, cities worldwide are increasingly seeking alternative planning approaches that emphasize sustainability, resilience, and human well-being [1].

In this context, the 15-minute city has gained global attention as a new urban paradigm. The concept proposes that residents should be able to access essential daily services—such as employment, education, healthcare, retail, and recreational spaces—within a 15-minute walk or bicycle ride from their homes. Rather than limiting mobility, the model aims to expand individual choice by reducing compulsory car dependence and strengthening local accessibility [2].

This paper critically analyzes the 15-minute city as a framework for sustainable urban living, focusing on its theoretical foundations, mobility implications, governance requirements, and practical limitations.

Literature review

The principles underlying the 15-minute city are rooted in earlier urban theories advocating compact, mixed-use, and walkable environments. Jacobs emphasized the importance of functional diversity and vibrant street life, while the New Urbanism movement promoted pedestrian-oriented neighborhood design. Building on these foundations, the 15-minute city introduces a temporal dimension to accessibility by evaluating urban performance in terms of travel time rather than physical distance [3, 4, 15].

Recent studies associate proximity-based urbanism with a wide range of environmental, social, and economic benefits. Walkable neighborhoods are linked to lower greenhouse gas emissions, reduced energy consumption, and improved air quality [5, 16]. Active mobility—particularly walking and cycling—also contributes to improved public health outcomes and lower rates of non-communicable diseases [6, 17]. Moreover, local accessibility strengthens neighborhood economies and social cohesion by encouraging local consumption and everyday social interaction [7, 18].

To operationalize proximity-based planning, several analytical frameworks have been developed, including the Flower of Proximity model. This framework evaluates accessibility across multiple daily-life dimensions such as education, healthcare, commerce, recreation, and mobility within defined time thresholds [15, 19]. Such multidimensional approaches allow planners to assess not only spatial proximity but also functional balance and equity in service distribution.

Despite its growing popularity, the 15-minute city concept has faced criticism. Some scholars argue that it oversimplifies complex urban systems and underestimates the need for city-wide and regional mobility, particularly for specialized services and employment sectors [8, 20]. Others warn that improvements in neighborhood accessibility may increase property values and accelerate gentrification if equity-oriented housing and land-use policies are not implemented simultaneously [9, 21, 25].

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2. Research methodology

This study adopts a qualitative and conceptual research methodology. Secondary data sources—including academic literature, international policy documents, and urban planning reports—are systematically reviewed to evaluate the principles and implementation strategies of the 15-minute city model.

A comparative case study approach is employed to examine cities where the concept has been actively implemented, particularly Paris and Vienna, and to assess its potential applicability in transitional urban contexts such as Tashkent.

The analytical framework focuses on four key dimensions:

- land use and spatial proximity;
- mobility systems;
- governance and policy instruments;
- social equity considerations.

This multidimensional approach enables a comprehensive assessment of both the opportunities and constraints associated with proximity-based urban planning [2]. The conceptual framework used in this study is illustrated in Figure 1.

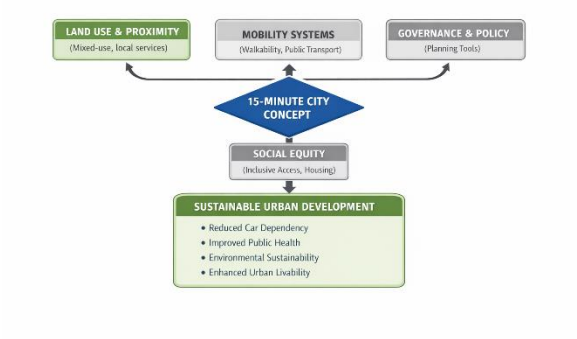

Fig. 1. Conceptual framework of the 15-minute city for sustainable urban development

3.1 Mobility and Accessibility in the 15-Minute City

Mobility plays a central role in the 15-minute city paradigm. The model prioritizes walking and cycling as primary modes of everyday travel, supported by high-quality public transport for longer-distance journeys.

Achieving this transition requires the reallocation of urban street space through wider sidewalks, protected bicycle lanes, traffic calming measures, and improved pedestrian safety [4, 10].

Public transport integration is essential to ensure that proximity-based neighborhoods remain connected to the broader urban system. Efficient, frequent, and accessible transit services allow residents to reach specialized services and employment opportunities beyond the 15-minute radius.

In addition, micromobility solutions—such as shared bicycles and e-scooters—can address first- and last-mile connectivity challenges and extend the functional reach of active mobility [11].

By reducing reliance on private automobiles, the 15-minute city contributes to lower carbon emissions, decreased traffic congestion, and improved urban air quality, supporting global climate and public health goals [5, 23].

3.2 Policy and Governance Implications

The successful implementation of the 15-minute city depends on supportive policy frameworks and effective governance structures.

While neighborhood-scale interventions are important, broader systemic challenges—including housing affordability, land-use regulation, and infrastructure investment—must be addressed at the city-wide level [12].

Key policy instruments include:

mixed-use zoning policies;

affordable housing regulations;

investments in public transport and pedestrian infrastructure;

protection of local services.

Participatory planning processes are equally critical, as they ensure that local communities are actively involved in decision-making and that urban transformation does not exacerbate existing social inequalities [7].

International examples demonstrate that proximity-based planning can be institutionalized through planning guidelines and evaluation tools. For instance, Melbourne's 20-minute neighbourhood policy provides a structured framework for assessing accessibility and guiding urban development [13, 24].

3.3 Case Studies: Paris, Vienna, and Transitional Cities

Paris is widely regarded as one of the most prominent examples of the 15-minute city in practice. Since 2020, the city has pursued a comprehensive urban transformation strategy aimed at decentralizing daily services and prioritizing proximity-based living. Major initiatives include the expansion of cycling infrastructure, pedestrianization of school streets, conversion of schoolyards into community spaces, and the creation of green infrastructure such as urban forests and pocket parks.

Vienna offers a complementary model of proximity-based urban development based on long-term strategic planning, a strong social housing system, and a highly efficient public transport network. The city's polycentric structure ensures that essential services—including education, healthcare, retail, and green spaces—are distributed across multiple neighborhood centers, reinforcing both accessibility and social equity [14].

To better illustrate the differences in planning approaches and urban structures among the selected cities, a comparative overview is presented in Table 1.

Table 1

Comparative Analysis of the 15-Minute City Implementation: Paris, Vienna, and Tashkent

Indicator	Paris (France)	Vienna (Austria)	Tashkent (Uzbekistan)
Urban planning paradigm	Explicit implementation of the 15-minute city concept	Polycentric compact city model	Transition from Soviet functional zoning toward mixed-use planning

Spatial structure	Dense urban fabric with decentralized neighborhood hubs	Polycentric structure with multiple local centers	Predominantly mono-functional residential districts
Land-use pattern	Strong mixed-use redevelopment	Stable mixed-use zoning	Predominantly separated land uses
Mobility priority	Walking, cycling, and public transport prioritized	Public transport and active mobility dominant	Private car use dominant
Cycling infrastructure	Rapidly expanding protected bicycle network	Well-developed cycling infrastructure	Fragmented and limited cycling facilities
Pedestrian environment	Pedestrianized streets and traffic-calmed zones	Wide sidewalks and pedestrian-friendly public spaces	Uneven pedestrian infrastructure
Public transport integration	Strong integration with proximity-based neighborhoods	Efficient city-wide public transport network	Existing network with limited integration with walkability
Green and public spaces	Urban forests, pocket parks, and schoolyard conversions	High-quality green spaces integrated into neighborhoods	Large green areas with uneven accessibility
Governance approach	Strong political leadership and policy support	Stable long-term planning institutions	Fragmented governance framework
Community participation	Participatory budgeting mechanisms	High level of public involvement	Informal participation through mahalla institutions
Housing and equity policy	Risk of gentrification; regulatory mitigation	Strong social housing system	Limited affordable housing policies
Overall implementation level	Fully implemented strategic model	Long-term proximity-based urban planning	Early-stage conceptual development

The comparison presented in Table 1 highlights significant differences in how proximity-based urban planning is implemented across the three cities. Paris demonstrates a rapid policy-driven transition toward the 15-minute city through active mobility policies and decentralized service provision. Vienna represents a stable and long-term proximity-oriented urban model supported by strong institutional frameworks and social housing policies. In contrast, Tashkent reflects the characteristics of a transitional urban context where mono-functional zoning patterns and increasing car dependency still dominate the urban structure.

In contrast, transitional cities—particularly those in Central Asia—face structural challenges that complicate the direct adoption of the 15-minute city model. Soviet-era planning traditions often resulted in mono-functional zoning, wide arterial roads, and spatial separation of residential and service areas. Nevertheless, neighborhood structures such as the mahalla system provide a valuable foundation for adapting proximity-based planning principles to local conditions.

To further evaluate accessibility to everyday services within the 15-minute city framework, the Flower of Proximity analytical model is applied. The comparative assessment of the selected cities is presented in Table 2.

Table 2

Flower of Proximity–Based Comparative Assessment of Paris, Vienna, and Tashkent

Indicator	Paris	Vienna	Tashkent
Education accessibility	Schools and childcare accessible within walking distance	Even distribution of educational facilities	Uneven distribution of educational services
Health services	Local clinics and pharmacies integrated in neighborhoods	Decentralized healthcare system	Primary healthcare available but uneven
Retail and daily services	Dense network of local shops and markets	Balanced local retail distribution	Retail concentrated along major corridors
Green spaces	Urban forests, pocket parks, and green corridors	Well-distributed parks and public spaces	Large green spaces with limited accessibility

Indicator	Paris	Vienna	Tashkent
Mobility	Strong cycling infrastructure and pedestrian priority	Integrated public transport and active mobility	Car-oriented mobility structure
Multimodal connectivity	Strong integration of micromobility and transit	Highly integrated multimodal transport	Limited integration between walking and transit
Equity of service distribution	High accessibility in most districts	Relatively uniform accessibility	Significant spatial inequality
15-minute accessibility	Most daily services accessible within 15 minutes	Services accessible within or near 15 minutes	Partial accessibility within 15 minutes
Implementation maturity	Advanced	Mature and stable	Early-stage development

The results summarized in Table 2 demonstrate that Paris and Vienna exhibit relatively balanced accessibility across most proximity indicators. In these cities, mixed-use development patterns, well-developed pedestrian environments, and integrated public transport systems allow residents to access essential services within short distances. In contrast, Tashkent displays a more uneven distribution of accessibility indicators, particularly in relation to mobility infrastructure and retail service integration. These findings indicate that improving walkability, strengthening multimodal transport integration, and promoting mixed-use development are essential steps for advancing proximity-based urban planning in transitional cities.

However, implementing such planning approaches requires significant investments in pedestrian and cycling infrastructure, mixed-use redevelopment, and stronger integration with public transport systems.

3. Conclusion

The historical and cultural heritage of Bukhara is a living testimony to many eras and civilizations. Past experience shows that successful preservation of monuments is possible only with a combination of respect for traditions, a scientific approach and modern technologies. In the context of globalization, urbanization and the growth of tourism, the task of preserving the authentic appearance of ancient Bukhara is becoming especially urgent. Responsibility for the future of the city lies with both specialists and the general public, for whom Bukhara is not just a tourist attraction, but a part of the world's cultural memory. The analysis shows that despite the significant efforts made in the 20th-21st centuries, the processes of preservation, reconstruction and restoration of historical sites face a number of serious problems. These include: inconsistency between modern engineering solutions and traditional construction technologies; lack of qualified specialists in the field of scientific restoration; destructive influence of natural factors and urbanization pressure; non-compliance with international standards in a number of restoration projects; commercialization and tourist pressure, leading to the loss of the authenticity of the historical environment. The future of historical Bukhara directly depends on a conscious attitude towards its cultural heritage. Only in the conditions of a scientifically grounded, ethically balanced and legally regulated approach is it possible to ensure the preservation of this unique civilizational phenomenon for future generations.

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Stress-dependent senomorphic-like activity of buckwheat-derived rutin mediated via SIRT1

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Abstract: Sirtuin 1 (SIRT1) is a key NAD⁺-dependent deacetylase regulating cellular metabolism, oxidative stress resistance, and longevity. This study investigates the senomorphic-like effects of buckwheat-derived rutin on SIRT1 under basal and toxic stress conditions. Using in vivo experiments in mice (liver and kidney tissues, n=8/group) and in silico molecular docking, we assessed SIRT1 protein levels and rutin interactions. BPA-induced stress decreased SIRT1 expression ($p < 0.05$), whereas co-treatment with buckwheat extract restored and elevated SIRT1 above control levels, indicating stress-responsive modulation. Docking analysis revealed strong binding of rutin to the SIRT1 catalytic site (up to –10.3 kcal/mol) with multiple hydrogen bonds, supporting direct modulatory potential. These findings suggest that buckwheat bioactives maintain homeostatic SIRT1 under normal conditions while enhancing its activity under stress, providing a potential dietary strategy to mitigate senescence-associated secretory phenotype (SASP)-related damage.

Keywords: SIRT1, buckwheat, senomorphic, rutin, molecular docking, oxidative stress, SASP

1. Introduction

Rapid Cellular senescence is a physiological process characterized by irreversible cell cycle arrest, contributing to age-related functional decline, chronic inflammation, tissue dysfunction, and the progression of degenerative diseases. Sirtuin 1 (SIRT1), an NAD⁺-dependent deacetylase, serves as a central regulator of this process by modulating cellular metabolism, mitochondrial function, autophagy, oxidative stress responses, and longevity pathways [1,2].

Beyond its canonical roles, SIRT1 exerts senomorphic effects: it modulates the senescence-associated secretory phenotype (SASP) in senescent cells by suppressing pro-inflammatory cytokines (e.g., IL-6, IL-8), proteases, and other factors without inducing cell death. This attenuates senescence-related tissue damage while preserving basal cellular function under normal conditions [3,4,5]. Reduced SIRT1 activity is associated with heightened SASP activation and accelerated cell cycle arrest, underscoring its protective role against senescence-driven pathology [6].

Natural polyphenols, particularly flavonoids such as rutin, have been shown to activate SIRT1 and exhibit context-dependent senomorphic activity. These compounds enhance cellular resilience to oxidative and metabolic stress by selectively upregulating SIRT1 under stress conditions while maintaining homeostatic expression in unstressed cells [7,8]. Rutin, a major flavonoid abundant in buckwheat (Fagopyrum esculentum), has demonstrated protective effects against oxidative stress and inflammation, partly through SIRT1-dependent pathways, including modulation of NF-κB signaling and improvement of mitochondrial function [9,10]. Rutin also reduces markers of cellular senescence in various models and suppresses aspects of SASP, supporting its potential as a senomorphic agent [11,12].

Buckwheat (*Fagopyrum esculentum*) is a rich dietary source of rutin and related bioactives, positioning it as a promising modulator of SIRT1-mediated senomorphic pathways [13,14,15]. However, the specific mechanisms by which buckwheat bioactives influence SIRT1 expression and activity particularly under stress versus basal conditions remain incompletely understood. Integrating in vivo expression analysis with in silico molecular docking provides a robust approach to characterize these interactions and the potential senomorphic effects of buckwheat flavonoids.

The aim of this study was to investigate the modulatory effects of buckwheat bioactives on SIRT1, quantify SIRT1 protein levels in liver and kidney tissues under basal and toxic stress conditions, and predict the molecular interactions of rutin with SIRT1 through docking analysis. By doing so, we sought to demonstrate the senomorphic potential of buckwheat bioactives and their role in protecting cells from stress-induced senescence.

2. Research methodology

1. Animals and Treatment Protocol

The experiment was conducted on laboratory mice maintained under standard conditions (12 h light/12 h dark cycle, 22 ± 2°C, ad libitum access to food and water). Animals were randomly assigned to four experimental groups (n = 8 per group):

1. **Control** — untreated, unstressed rats.
2. **BKW-STW** — mice treated with buckwheat extract alone.
3. **BPA-STP** — mice exposed to bisphenol A (BPA) to induce toxic stress.
4. **BKW-BPA** — mice treated with both buckwheat extract and BPA.

Treatments were administered orally at predetermined doses for 25 consecutive days. All procedures followed national and international ethical guidelines for animal experimentation.

2. In Vivo SIRT1 Expression Analysis

At the end of the treatment period, animals were

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anesthetized, and liver and kidney tissues were collected. Tissue samples were homogenized, and SIRT1 protein levels were quantified using an ELISA kit according to the manufacturer's instructions. Protein concentrations were expressed as ng/mg of total protein.

Statistical Analysis: Data were presented as Mean ± SEM. One-way ANOVA followed by Tukey's post-hoc test was used to assess differences among groups. Statistical significance was defined as $p < 0.05$.

3. *In Silico* Molecular Docking

- **Ligands:** Major buckwheat flavonoid -rutin.
- **Receptor:** 3D structure of SIRT1 obtained from the Protein Data Bank (PDB).
- **Docking Tool:** CB-Dock2 was used to predict ligand binding to the SIRT1 catalytic site.
- **Evaluation Criteria:**
  - Binding affinity (kcal/mol)
  - Formation of hydrogen bonds and interactions with key catalytic residues

Docking results were visualized to confirm the stability of ligand–SIRT1 interactions, providing insight into the direct modulatory potential of buckwheat flavonoids.

4. Ethical Considerations

All animal experiments were conducted in accordance with the guidelines of the National and International Committees for Laboratory Animal Care. ELISA and in silico procedures adhered to standard biosafety protocols.

4. Results ad discussion

1. SIRT1 Expression in Liver and Kidney

SIRT1 protein levels in liver and kidney tissues varied significantly among the experimental groups (Table 1).

Table 1

SIRT1 protein levels in liver and kidney tissues (Mean ± SEM, ng/mg protein)

Group	Liver	Kidney
Control	4.34 ± 0.21	5.40 ± 0.04
BKW-STW	3.94 ± 0.08	4.73 ± 0.16
BPA-STP	3.73 ± 0.10	4.65 ± 0.14
BKW-BPA	4.67 ± 0.19*	5.91 ± 0.10*

BPA treatment significantly reduced SIRT1 expression in both liver and kidney ($p < 0.05$), reflecting toxic stress-induced downregulation. Buckwheat treatment alone (BKW-STW) slightly decreased SIRT1 in unstressed tissues, consistent with context-dependent negative feedback. Co-treatment with buckwheat and BPA (BKW-BPA) restored and enhanced SIRT1 expression, exceeding control levels ($p < 0.05$), indicating stress-responsive senomorphic activity.

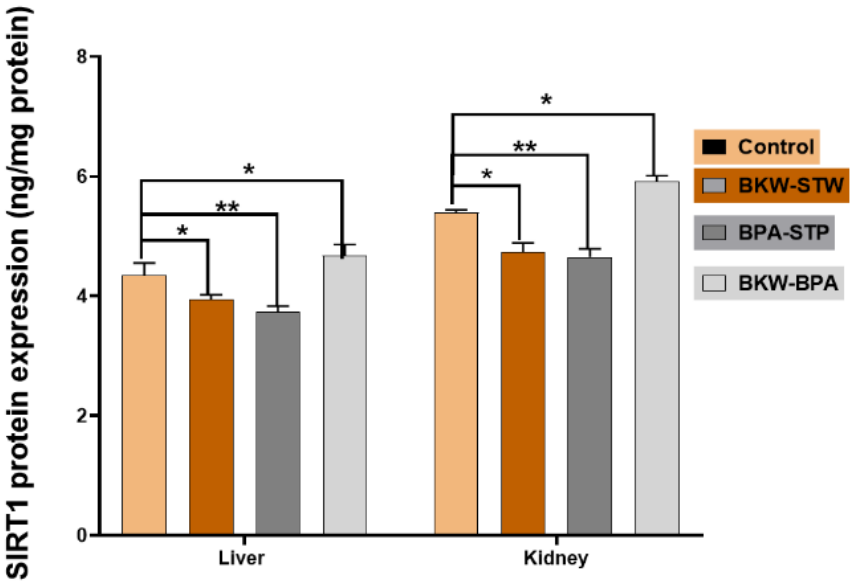

Fig. 1. SIRT1 protein levels in liver and kidney tissues. Statistical significance between groups is indicated (*p < 0.05, **p < 0.01)

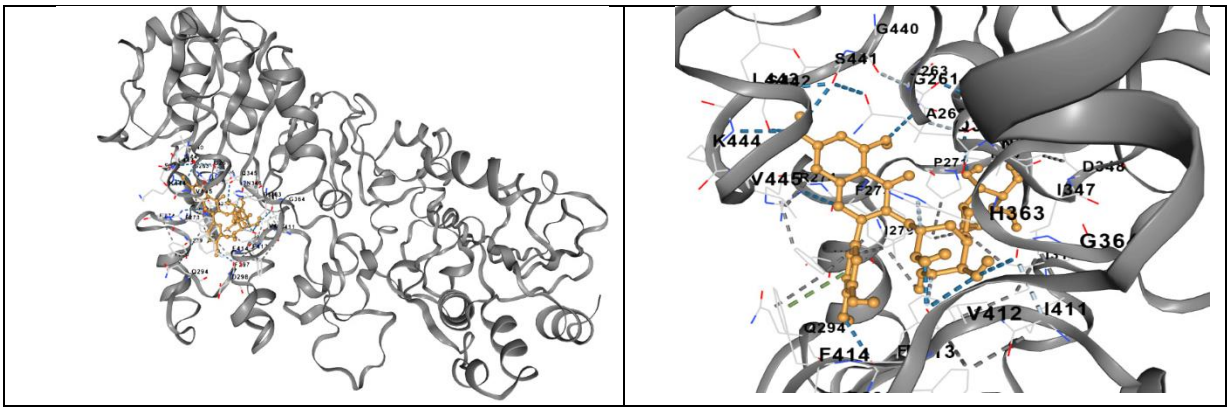

Fig. 2. 3D molecular docking of Rutin with SIRT1

2. ***In Silico* Docking Analysis**

Molecular docking of buckwheat flavonoids revealed stable interactions with the SIRT1 binding site.

The docking analysis identified several potential binding pockets of SIRT1 interacting with Rutin (Table 1). Among them, pocket C2 exhibited the highest binding affinity at –10.3 kcal/mol, with a large volume of 4052 Å³ and centered at coordinates (10, –2, 19), indicating a spacious and energetically favorable site for ligand accommodation. Pockets C3, C5, C4, and C1 showed slightly lower affinities (–8.7 to –8.0 kcal/mol), with variable volumes and positions, suggesting multiple potential binding sites that may contribute to the modulatory effect of Rutin.

Table 2

Binding affinities, pocket volumes, and docking coordinates of Rutin with SIRT1

Pocket ID	Affinity (kcal/mol)	Volume (Å³)	Center (x,y,z)	Docking Size(x,y,z)
C2	–10.3	4052	(10, –2, 19)	(25, 33, 31)
C3	–8.7	2827	(19, –17, 27)	(25, 33, 25)
C5	–8.7	485	(40, –8, 26)	(25, 25, 25)
C4	–8.4	646	(30, –21, 27)	(25, 25, 25)
C1	–8.0	4407	(43, –27, 18)	(25, 35, 32)

Rutin formed multiple hydrogen bonds with key catalytic residues of SIRT1, supporting a direct modulatory effect on SIRT1 activity. These interactions provide a structural basis for the observed in vivo senomorphic effects, as flavonoids may enhance SIRT1 activity under stress conditions without affecting basal levels.

3. Integrated Analysis

The combination of in vivo and in silico data demonstrates that buckwheat bioactives exhibit senomorphic properties:

1. Stress-free conditions (BKW-STW): SIRT1 expression is slightly decreased, maintaining homeostasis.
2. Toxic stress (BPA-STP): SIRT1 expression decreases due to oxidative stress.
3. Stress + Buckwheat (BKW-BPA): SIRT1 is restored and enhanced, indicating stress-responsive senomorphic activity.
4. Docking evidence: Rutin binds stably to SIRT1, supporting direct modulation.

These results suggest that buckwheat bioactives can selectively modulate SIRT1, protecting cells from SASP-related damage under stress while maintaining basal function under normal conditions.

Cellular senescence is a hallmark of aging and contributes to tissue dysfunction, chronic inflammation, and increased susceptibility to degenerative diseases. SIRT1, a NAD^+-dependent deacetylase, has emerged as a key regulator of senescence, oxidative stress response, and metabolic homeostasis [1,2]. Beyond its canonical roles, SIRT1 has been implicated in senomorphic activity, whereby it modulates the senescence-associated secretory phenotype (SASP) without inducing cell death, thereby attenuating pro-inflammatory signaling and tissue damage [3,4,5].

In the present study, we demonstrate that buckwheat bioactives exert context-dependent, senomorphic effects on SIRT1. In unstressed tissues, buckwheat treatment (BKW-STW) slightly decreased SIRT1 expression relative to control, consistent with homeostatic regulation and negative feedback mechanisms. This suggests that buckwheat flavonoids do not overactivate SIRT1 in basal conditions, preventing potential metabolic imbalance. Conversely, under BPA-induced toxic stress, SIRT1 expression was significantly reduced (BPA-STP), reflecting oxidative and metabolic perturbations. Co-treatment with buckwheat (BKW-BPA) restored and further enhanced SIRT1 levels, indicating stress-responsive modulation and supporting a senomorphic mechanism [13].

In silico docking analysis provides structural insights into this modulatory activity. Rutin exhibited favorable binding energy (–10.2 kcal/mol,) and formed stable hydrogen bonds with key catalytic residues of SIRT1. These findings suggest that the flavonoid act as direct modulators, enhancing SIRT1 activity under stress conditions, which aligns with the observed *in vivo* restoration of protein levels [15]. Importantly, this direct interaction likely underpins the selective senomorphic activity, whereby SIRT1-mediated suppression of SASP reduces inflammatory signaling in stressed cells without affecting normal cellular function.

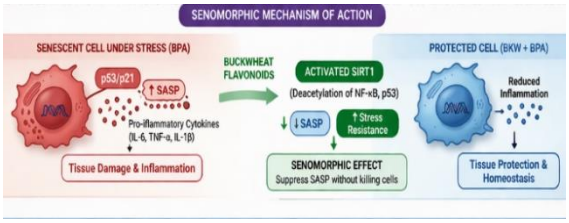

Fig. 3. Role of SIRT1 in the senomorphic mechanism mediated by buckwheat flavonoids

Previous studies have reported similar senomorphic effects for polyphenols such as resveratrol and quercetin, which enhance SIRT1 activity, mitigate SASP factors, and protect tissues from age- or toxin-induced damage [16]. Our results extend these findings by demonstrating that buckwheat-derived flavonoids can modulate SIRT1 in a tissue-specific and stress-dependent manner, highlighting their potential as natural senomorphic agents [17].

The integrated *in vivo* and *in silico* approach strengthens the mechanistic understanding of buckwheat flavonoids. Restoration of SIRT1 in liver and kidney under toxic stress, coupled with stable ligand–receptor interactions in silico, provides compelling evidence that the senomorphic effects are mediated by direct SIRT1 modulation, rather than indirect antioxidant effects alone. This distinction is critical for designing senomorphic interventions, as it emphasizes selective modulation of senescence-associated pathways without cytotoxicity.

Overall, these findings support the concept that buckwheat bioactives confer protective senomorphic effects through SIRT1, preserving tissue homeostasis under normal conditions and enhancing stress resilience. Such compounds may have translational potential in preventing or mitigating senescence-associated tissue dysfunction and toxicity-induced cellular damage.

5. Conclusion

This study demonstrates that buckwheat (*Fagopyrum esculentum*) bioactives, particularly rutin and quercetin, exert senomorphic effects through the selective modulation of SIRT1. Key findings include:

1. Under normal, unstressed conditions, buckwheat maintains basal SIRT1 expression, preventing unnecessary overactivation and supporting cellular homeostasis.
2. Under BPA-induced toxic stress, SIRT1 expression is downregulated, but co-treatment with buckwheat restores and enhances SIRT1 levels, demonstrating stress-responsive senomorphic activity.
3. In silico docking confirms that rutin binds stably to SIRT1's catalytic site, providing mechanistic evidence for direct modulation of SIRT1 activity.
4. Overall, buckwheat bioactives suppress stress-induced SASP and inflammatory signaling without inducing cell death, highlighting their potential as natural senomorphic agents.

These results support the concept that buckwheat-derived flavonoids can enhance cellular resilience and protect tissues from senescence-associated dysfunction, offering a promising dietary or therapeutic approach for age- and toxin-related cellular stress. Future studies should explore long-term effects and translational applications in models of chronic senescence and metabolic dysfunction.

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Influence of silica gel dispersion and superplasticizer on the properties of cement paste

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Abstract: The influence of the dispersion and content of ground silica gel on the properties of cement paste in the presence of a polycarboxylate-based superplasticizer was investigated. Silica gel was introduced in amounts of 5, 10, and 15% by mass of cement, while the superplasticizer dosage was 1%. It was established that an increase in the fineness of silica gel promotes the intensification of hydration processes and the formation of a denser cement paste structure. It was shown that the optimal silica gel content is 5%, at which the maximum strengthening effect is achieved. The incorporation of the superplasticizer reduces the water-to-cement ratio and enhances the compressive strength of the cement paste; however, it is accompanied by an increase in setting time. The highest strength was obtained for the composition containing 5% finely dispersed silica gel and 1% superplasticizer. The observed effect is attributed to the combined action of the additives and the densification of the cement paste structure.

Keywords: silica gel, fineness, cement paste, superplasticizer, water-to-cement ratio, compressive strength, setting time, modification of cementitious systems

1. Introduction

The development of non-autoclaved foamed concrete is associated with the need to improve the strength characteristics and structural homogeneity of the cement paste while simultaneously reducing the material density. One of the most effective approaches is the use of active mineral additives capable of participating in pozzolanic reactions and promoting the formation of additional calcium silicate hydrate (C–S–H) phases [1, 2].

The pozzolanic activity of silica-containing materials is governed by their interaction with calcium hydroxide, leading to the formation of low-basic calcium silicate hydrates, which contribute to the densification of the cement paste structure and an increase in its strength [3]. The intensity of these processes is largely determined by the fineness of the additive and the content of amorphous silicon dioxide [4].

Silica fume is the most widely used silica-containing additive, as it accelerates cement hydration, reduces the content of portlandite, and contributes to the formation of a denser microstructure [5]. At the same time, studies show that the efficiency of such additives strongly depends on their dosage; exceeding the optimal content leads to a dilution effect in the cement system [6].

In recent years, increasing attention has been paid to the use of silica gel as an alternative source of amorphous SiO_2. Due to its high specific surface area and reactivity, silica gel can активно вступать в пуццолановую реакцию, способствуя дополнительному образованию C–S–H-фазы [7]. However, the effect of silica gel fineness on the properties of cement paste remains insufficiently studied, especially under conditions of complex modification.

An additional factor influencing structure formation processes is the use of superplasticizers, which affect hydration kinetics, the water-to-cement ratio, and setting time [8]. However, the combined effect of silica gel fineness and superplasticizer on the properties of cementitious systems requires further investigation.

In this regard, the aim of this study is to investigate the effect of the fineness and content of ground silica gel on the setting time and strength characteristics of cement paste in the presence of a superplasticizer.

2. Materials and methods

Portland cement CEM II/A-K (Z-I) 42.5N produced by JSC “Ahangarancement” was used as the binder.

Technical silica gel was used as a mineral additive and ground under laboratory conditions in a ball mill to three levels of fineness: 9215, 4310, and 1866 cm^2/g. Different degrees of fineness were achieved by varying the grinding duration. The obtained powders were characterized by different specific surface areas, determined using a PVKh-11A apparatus, which made it possible to evaluate the effect of fineness on the reactivity of the additive.

A polycarboxylate-based superplasticizer of German origin (“Master Glenium”) was used as a chemical admixture to regulate the rheological properties of the mixture. The dosage of the superplasticizer was 1% by mass of cement and was selected based on preliminary experimental studies as optimal, ensuring effective water reduction without adverse effects on hydration processes and the strength characteristics of the cement paste.

The water-to-cement ratio was adjusted for each composition according to the standard consistency, determined by the Vicat method (with plunger) in accordance with GOST 310.3–76, which ensured identical rheological conditions and the reliability of the comparative analysis of the studied systems.

The initial and final setting times were determined using the Vicat method with a needle in accordance with GOST 310.3–76 “Cements. Methods for determination of standard consistency, setting time, and soundness.”

The initial setting time was defined as the moment when the Vicat needle failed to reach the bottom of the mould by

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1–2 mm, while the final setting time corresponded to a penetration depth of not more than 1 mm.

All measurements were carried out at a temperature of (20±2) °C.

Cube specimens with dimensions of 20×20×20 mm were prepared from the investigated compositions and kept in moulds for 24 hours. After demoulding, the specimens were stored in a standard curing chamber at a temperature of (20±2) °C and a relative humidity of at least 95%, in accordance with GOST 10180–2012.

For convenience of analysis, the investigated compositions were designated as follows:

R — cement paste without additives; **SP** — cement paste with superplasticizer Master Glenium (1% by mass of cement); **SG5C** — cement paste with silica gel (5%) and superplasticizer Master Glenium (1%);

FSG — compositions with finely dispersed silica gel; **MSG** — compositions with medium-dispersed silica gel; **CSG** — compositions with coarsely dispersed silica gel.

Within each series, the silica gel content was 5, 10, and 15% by mass of cement. The content of additives is given as a percentage of the cement mass.

Compressive strength was determined at the age of 28 days using a hydraulic press (model to be specified) in accordance with GOST 10180–2012.

The tests were carried out on six parallel specimens for each composition.

3. Results and Discussion

It was established that the fineness of ground silica gel has a significant effect on the structure formation processes of the cement paste. The appearance of silica gel with different degrees of fineness is shown in Figure 1.

An increase in grinding time leads to a reduction in particle size and an improvement in powder homogeneity, indicating an increase in the specific surface area of the material.

The water-to-cement ratio for the investigated compositions was selected in accordance with the standard consistency of the cement paste. The obtained W/C values are presented in Table 1.

The greatest increase in the W/C ratio was observed for compositions with finely dispersed silica gel, which is attributed to its high specific surface area.

Despite the increase in the water-to-cement ratio with the incorporation of silica gel, an increase in compressive strength is observed, confirming the active participation of silica gel in the pozzolanic reaction and its strengthening effect.

a) unground b) coarsely ground c) medium-ground d) finely ground

Fig.1. Appearance of silica gel with different degrees of finenes

Table 1

Composition of cement mixtures and their water-to-cement ratio determined based on standard consistency

№	Composition	W/C	Silica gel, % by cement mass	Silica gel, g	Penetration depth , mm*
1	R	0,30	–	–	5
2	FSG	0,32	5	20	6
3		0,34	10	40	6
4		0,38	15	60	5
5	MSG	0,32	5	20	5
6		0,34	10	40	6
7		0,37	15	60	6
8	CSG	0,32	5	20	5
9		0,33	10	40	5,5
10		0,33	15	60	6

** Distance between the Vicat plunger and the bottom of the mould.*

The results of compressive strength tests at the age of 28 days are presented in Figure 2.

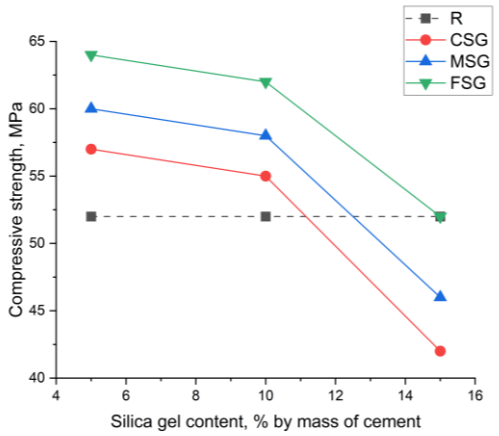

Fig. 2. Effect of silica gel content and fineness on the compressive strength of cement paste

It was established that the incorporation of silica gel leads to an increase in the compressive strength of the cement paste, while the magnitude of the effect depends on both the content of the additive and its fineness.

At a silica gel content of 5%, the strength increase reaches up to 9–10% for coarsely dispersed, up to 15% for medium-dispersed, and up to 23% for finely dispersed material compared to the reference composition.

With an increase in silica gel content to 10%, the effect is maintained; however, the magnitude of the strength gain slightly decreases, amounting to approximately 6%, 11%, and 19%, respectively.

A further increase in content to 15% results in a reduction in strength, reaching up to 19% for coarsely dispersed and up to 11% for medium-dispersed silica gel, whereas for finely dispersed material the strength remains at the level of the reference composition.

It should be noted that the increase in strength occurs despite the rise in the water-to-cement ratio, which indicates the active progression of the pozzolanic reaction and the formation of additional C–S–H phase, leading to densification of the cement paste structure.

It was established that the optimal silica gel content is 5%, with the maximum strengthening effect observed when finely dispersed silica gel is used.

Based on the obtained results, further studies were carried out for compositions with the indicated silica gel content, incorporating a polycarboxylate superplasticizer in an amount of 1% by mass of cement to evaluate their combined effect on hydration processes, setting time, and strength characteristics of the cement paste.

The results of setting time determination for the selected compositions are presented in Table 2.

Table 2

Water-to-cement ratio, compressive strength, and setting time of cement paste composition

Composition	W/C	Compressive strength at 28 days, MPa	Initial setting time	Final setting time
R	0,3	52,3	2 h 10 min	2 h 50 min
SP	0,21	59,62	6 h 40 min	3 h 30 min
SG5C	0,22	95,4	5 h 25 min	4 h 55 min

It was established that the incorporation of the MasterGlenium superplasticizer (1%) leads to a significant increase in the initial setting time compared to the reference composition, indicating its retarding effect.

The addition of 5% silica gel in the presence of the superplasticizer contributes to a reduction in the initial setting time, which is attributed to its high fineness and the acceleration of hydration processes.

A similar trend is observed for the final setting time.

It was shown that the superplasticizer exerts a retarding effect on the setting processes, whereas silica gel partially compensates for this effect.

The test results demonstrated that the incorporation of the superplasticizer leads to an increase in the compressive strength of the cement paste, which is consistent with literature data and is attributed to a reduction in the water-to-cement ratio and densification of the structure.

The highest strength was observed for the SG5C composition containing 5% silica gel and 1% superplasticizer. The strength increase is approximately 60% compared to the SP composition.

The observed effect is explained by the combined action of the additives. The superplasticizer reduces the water-to-cement ratio, while finely dispersed silica gel, owing to its high specific surface area, intensifies the pozzolanic reaction, leading to additional formation of the C–S–H phase. Similar trends in strength enhancement with the incorporation of silica-containing additives have been reported in several studies [2, 4, 5].

It was observed that the combined use of the superplasticizer and silica gel provides a pronounced synergistic effect and results in a significant increase in the strength of the cement paste.

Thus, the use of ground silica gel in combination with a superplasticizer is an effective approach for modifying cementitious binders and can be recommended for application in non-autoclaved foamed concrete.

4. Conclusion

The results obtained demonstrate that the fineness and content of silica gel have a significant effect on the properties of cement paste.

It was shown that an increase in silica gel fineness enhances its reactivity and intensifies the pozzolanic reaction. The optimal silica gel content is 5% by mass of cement, at which the maximum strengthening effect is achieved.

It was found that the incorporation of a polycarboxylate-based superplasticizer at a dosage of 1% reduces the water-to-cement ratio and increases the compressive strength of the cement paste; however, it is accompanied by an increase in setting time.

It was demonstrated that the combined use of the superplasticizer and finely dispersed silica gel provides a pronounced synergistic effect, resulting in a significant increase in strength while maintaining the workability of the mixture.

The obtained results are consistent with X-ray diffraction analysis data, confirming a decrease in portlandite content and an increase in the proportion of amorphous C–S–H phase.

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Application of digital twin technology for monitoring residential buildings

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Abstract: The rapid digitalization of the construction industry has led to the development of advanced technologies for monitoring and managing the condition of buildings and infrastructure. One of the most promising approaches is Digital Twin technology, which creates a dynamic digital representation of a physical object by integrating digital models with real-time monitoring data. This study investigates the application of Digital Twin technology for monitoring residential buildings in Uzbekistan, a region characterized by high seismic activity. The proposed framework integrates Building Information Modeling (BIM), sensor-based Structural Health Monitoring (SHM), and cloud-based data analytics to provide continuous assessment of structural performance. The methodology includes the development of a detailed BIM model of the building, the installation of a network of structural and environmental sensors, and the integration of collected data into a digital twin platform for real-time analysis and visualization. The system enables monitoring of vibration characteristics, deformation, and environmental effects on structural elements. The results demonstrate that the integration of digital models, sensor networks, and artificial intelligence technologies allows early detection of structural anomalies, supports predictive maintenance strategies, and improves the reliability and safety of residential buildings. The proposed approach can serve as a technological basis for developing digital seismic passports of buildings and implementing smart infrastructure monitoring systems in Uzbekistan and other seismically active regions.

Keywords: digital twin, structural health monitoring, BIM, seismic monitoring, residential buildings, sensor networks, predictive maintenance, smart infrastructure

1. Introduction

One of the most promising directions in the digitalization of the construction industry is **Digital Twin technology**. A digital twin represents a highly accurate virtual counterpart of a physical object that is created based on digital models and continuously updated using data obtained from sensor-based monitoring systems [1]. Unlike traditional **Building Information Modeling (BIM)** models, a digital twin functions as a dynamic system that ensures synchronization between the physical object and its virtual representation in real time [3]. In civil engineering, digital twin technology is actively applied to address problems related to **structural health monitoring and assessment of the technical condition of building structures**. The integration of sensors measuring acceleration, deformation, temperature, and vibration with digital building models enables continuous analysis of the dynamic behavior of structures and prediction of potential structural damage [2]. These technologies are particularly important in **seismically active regions**, where rapid evaluation of structural performance under dynamic loading is required. Structural health monitoring systems integrated with digital twins allow the analysis of dynamic characteristics such as **natural frequencies, mode shapes, and damping ratios**, which may indicate changes in structural stiffness and possible damage [4]. Recent studies show that the integration of digital twins with sensor-based monitoring systems can significantly improve structural condition assessment and enable **predictive maintenance strategies** [1]. Such systems allow early detection of structural defects, reduction of maintenance costs, and improvement of the reliability of building structures.

Literature Review

Digital Twin Technology in Civil Engineering

The concept of **Digital Twin (DT)** has emerged as a transformative approach in civil engineering, allowing the creation of high-fidelity digital replicas of physical structures. Unlike traditional BIM models, a digital twin operates dynamically, continuously integrating real-time sensor data to represent the current state of a structure and predict its behavior under operational or environmental loads (Fuller & Fan, 2020) [6].

Digital twin systems facilitate continuous structural monitoring by integrating networks of accelerometers, strain gauges, temperature, and vibration sensors with analytical models. Such integration allows early detection of deviations from expected performance, identification of structural damage, and implementation of predictive maintenance strategies [7].Recent studies demonstrate that combining laser scanning technology with DT frameworks significantly improves the accuracy of as-built models and structural deformation monitoring. For example, Yashinsky et al. (2014) utilized laser scanning for post-earthquake bridge inspections, highlighting its effectiveness in detecting subtle geometric changes and structural anomalies [8]. Similarly, Takhirov & Kayen (2021) compared point clouds generated by terrestrial laser scanning and photogrammetric methods, showing that DT models based on laser scanning provide higher fidelity for structural analysis [9].

Structural Health Monitoring (SHM) for Seismic Regions

Structural Health Monitoring (SHM) is a key application of digital twins, particularly in seismically active regions. SHM systems record structural vibrations, natural frequencies, mode shapes, and damping ratios, enabling early detection of stiffness reductions and potential damage [10].The integration of DT and SHM allows continuous

evaluation of structural integrity under dynamic loads. For instance, studies on reinforced concrete and steel bridges show that DT-based SHM can predict post-earthquake performance, optimize maintenance schedules, and extend the service life of infrastructure (Takhirov et al., 2021) [11]. Furthermore, real-time monitoring enables engineers to respond promptly to critical changes in building performance, ensuring occupant safety in high-risk seismic zones (Takhirov, 2021) [12].

Regional Research in Central Asia

Research on Structural Health Monitoring (SHM) and Digital Twin technologies in Central Asia is becoming increasingly important due to the region's high seismic activity and rapid urban development. In Uzbekistan, several studies have focused on the application of advanced monitoring technologies for infrastructure safety. For instance, Takhirov et al. (2020–2025) applied terrestrial laser scanning and vibration sensors for bridge monitoring in Tashkent, demonstrating that point cloud data can effectively detect geometric imperfections and support the creation of digital twins for predictive maintenance [9]. Similarly, Rashidov et al. (2020) presented a comprehensive program for the structural assessment of bridges, emphasizing the importance of integrating SHM systems to improve seismic risk mitigation strategies [10]. In Kazakhstan, research has explored the use of modern sensor technologies and data analysis methods for structural monitoring. Yusupov and Suleimenov (2022) implemented wireless sensor networks and inertial measurement units (IMUs) to monitor building vibrations under seismic loads, integrating the collected data into predictive maintenance models [11]. Furthermore, Akhmetov et al. (2023) applied statistical and machine learning algorithms to analyze the dynamic responses of buildings in Almaty, demonstrating the potential for automated SHM systems within digital twin frameworks [12]. Studies in Kyrgyzstan and Tajikistan have also contributed to this field. Ismanova (2021) investigated the seismic response of residential buildings using modal frequency analysis, which aligns with SHM methodologies used in digital twin modeling [13]. In addition, Yusufova (2023) examined vibration-based monitoring techniques for residential buildings, highlighting their importance for early warning systems and damage detection in seismically active regions [14].

2. Materials and methods

The proposed Digital Twin system for residential buildings consists of three interrelated components: a digital building model based on Building Information Modeling (BIM), a structural monitoring sensor network, and a data analytics platform that enables real-time analysis and predictive diagnostics. The integration of these components allows the creation of a dynamic digital representation of the physical building, which continuously updates based on real operational data and supports informed decision-making for maintenance and safety management.

Digital Building Model

The digital representation of the building is developed using BIM software such as **Autodesk Revit**. The BIM model contains comprehensive and structured information about the building and serves as the foundational layer for the Digital Twin system. It includes detailed data on structural geometry, such as columns, beams, slabs, and shear walls, which define the load-bearing framework of the structure. In addition, the model incorporates information on material properties, including strength characteristics, density, elasticity, and durability parameters of construction materials. The BIM environment also stores architectural information, such as floor plans, spatial configuration, façade systems, and internal layout of residential units. Furthermore, engineering systems—including Mechanical, Electrical, and Plumbing (MEP) components—are integrated into the model. This includes ventilation systems, electrical networks, water supply pipelines, and heating infrastructure. By combining these datasets, the BIM model provides a comprehensive digital representation of the building that supports structural analysis, maintenance planning, and integration with monitoring technologies. Within the Digital Twin framework, the BIM model acts as a reference model that is continuously updated based on sensor data obtained from the physical structure.

Sensor Monitoring Network

To monitor the structural performance of the building in real time, a network of embedded and surface-mounted sensors is installed in critical structural elements. These sensors collect continuous data on the physical state and dynamic behavior of the building. The monitoring system may include accelerometers to measure structural vibrations and dynamic responses, strain gauges to detect deformation in structural members, displacement sensors to monitor movement or settlement, and environmental sensors to record temperature and humidity conditions that may influence material behavior. The placement of sensors is determined based on structural analysis and critical load-bearing zones of the building, such as foundations, columns, shear walls, and floor slabs. During seismic events or dynamic loads, the sensors capture vibration characteristics, including frequency, amplitude, and acceleration responses. This information allows engineers to evaluate structural performance and detect early signs of damage or structural degradation.

Sensor data are transmitted in real time to cloud-based data processing systems using Internet of Things (IoT) communication protocols. Through wireless communication technologies, the collected data are continuously synchronized with the Digital Twin platform. The integration of real-time monitoring data with the digital model enables the visualization of structural behavior, automatic detection of anomalies, and the development of predictive maintenance strategies aimed at improving the safety and resilience of residential buildings, particularly in seismically active regions.

3. Results and Discussion

The figure illustrates the integrated system for monitoring, diagnosing, and analyzing transport infrastructure, buildings, and engineering structures using mobile laboratories, 3D scanning technologies, artificial intelligence, and digital twin modeling. At the first stage, field data are collected using a mobile laboratory equipped with modern measurement instruments, including drones, 3D scanners, and cameras. These tools are used to perform instrumental inspections and 3D scanning of buildings,

structures, and transport infrastructure, allowing researchers to obtain accurate geometric and structural data. The collected information is then transferred to the scientific and practical laboratory at the university, where it is processed in a modern simulation laboratory equipped with high-performance computers and specialized software. At this stage, computational analysis and structural modeling are performed. The processed data are further analyzed in the Artificial Intelligence Laboratory (AI Lab). Using artificial intelligence algorithms, the system creates a digital twin of the building or structure, which represents a virtual model that reproduces the real object's physical and structural characteristics. Based on the digital twin, advanced simulations and analytical calculations are carried out to assess the condition and behavior of structures under different loads, including seismic impacts. As a result, the system provides several important outputs:

• Non-destructive diagnostics of buildings and structures using artificial intelligence technologies

• Creation of digital seismic passports for buildings and transport infrastructure

• Development of seismic-resistant structural solutions to improve safety and reliability

Thus, the presented scheme demonstrates a closed technological cycle that integrates field measurements, digital modeling, artificial intelligence, and engineering analysis to support modern infrastructure monitoring and structural safety assessment.

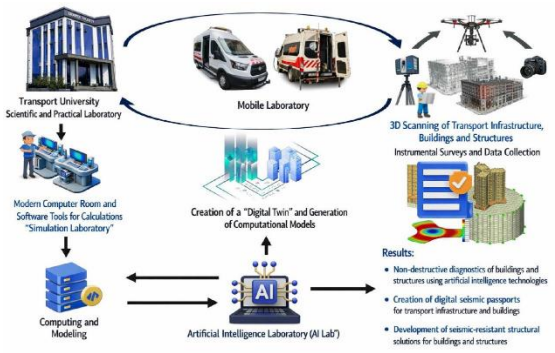

Fig. 1. Transport infrastructure, buildings and structures "Digital twin" scheme of simulation modeling of seismic effects

4. Conclusion

This study presented the concept and methodological framework of a Digital Twin–based monitoring system for residential buildings in Uzbekistan, integrating Building Information Modeling (BIM), sensor-based Structural Health Monitoring (SHM), and advanced data analytics technologies. The proposed approach demonstrates how digital models, real-time sensor data, and analytical platforms can be combined to create a dynamic representation of a building that continuously reflects its physical condition.

The results indicate that the integration of BIM models with sensor monitoring networks enables continuous observation of structural behavior, including vibration characteristics, deformation patterns, and environmental influences. Such integration improves the ability to detect structural anomalies at an early stage and provides a reliable basis for assessing the technical condition of buildings, particularly in seismically active regions. The use of cloud-based data transmission and Internet of Things (IoT) technologies ensures real-time synchronization between the physical structure and its digital counterpart. The analytical platform of the Digital Twin system further enhances monitoring capabilities by applying signal processing, modal analysis, and machine learning algorithms to interpret structural data and identify abnormal patterns. This enables predictive maintenance strategies and supports informed decision-making regarding building safety, maintenance planning, and lifecycle management.

T he developed monitoring scheme also demonstrates the effectiveness of integrating field inspection technologies, such as mobile laboratories, 3D scanning, and drone-based data collection, with artificial intelligence and digital modeling tools. This integrated workflow allows the creation of digital seismic passports for buildings and infrastructure, supports non-destructive structural diagnostics, and provides a basis for the development of improved seismic-resistant design solutions.

Overall, the proposed Digital Twin framework offers a promising approach for improving the monitoring, safety, and resilience of residential buildings in Uzbekistan. The implementation of such systems can contribute to the development of smart infrastructure management practices and enhance the reliability of buildings exposed to seismic hazards. Future research should focus on the practical implementation of pilot Digital Twin systems, expansion of sensor networks, and the development of advanced AI-based algorithms for automated structural damage detection and risk assessment.

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Enhancing women's leadership in science and innovation

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Abstract: Enhancing women's leadership in science and innovation has become a critical priority in the context of global knowledge economies and sustainable development. Despite notable progress in women's access to education, their representation in leadership positions within stem fields remains limited. This paper examines the structural, socio-cultural, and institutional barriers that hinder women's advancement into leadership roles in science and innovation. Drawing on interdisciplinary research and global data, the study identifies key challenges, including gender stereotypes, limited access to professional networks, lack of mentorship, and organizational biases. Furthermore, the paper explores how these barriers contribute to underutilization of women's potential in innovation ecosystems. The findings highlight that inclusive leadership is essential for enhancing creativity, improving decision-making, and ensuring more equitable and effective scientific outcomes. In response, the study proposes a set of strategic recommendations, including leadership development programs, gender-sensitive policies, mentorship initiatives, and institutional reforms aimed at fostering inclusive environments. The paper concludes that strengthening women's leadership in science and innovation is not only a matter of equity but also a strategic driver of sustainable and inclusive development.

Keywords: women's leadership, science and innovation, gender equality, stem, leadership development, innovation systems, women in stem

1. Introduction

In the contemporary era of knowledge-driven economies, science and innovation have become central to sustainable development, global competitiveness, and technological advancement. Leadership within these domains plays a decisive role in shaping research agendas, guiding innovation processes, and influencing policy directions. However, despite significant progress in expanding women's access to education and participation in the workforce, a substantial gender gap persists in leadership positions within science and innovation systems. Women remain underrepresented not only in STEM fields but particularly in decision-making roles, senior academic positions, and innovation leadership structures.

This imbalance reflects deeper structural and socio-cultural inequalities that extend beyond access to education. While women increasingly enroll in higher education and, in some regions, achieve parity with men in overall academic attainment, their progression into leadership roles remains limited. This phenomenon is often described as the "glass ceiling," referring to invisible barriers that prevent women from advancing to top positions despite adequate qualifications and performance. In the context of science and innovation, these barriers manifest in various forms, including limited access to research funding, underrepresentation in high-impact publications, exclusion from professional networks, and biased evaluation systems.

Furthermore, leadership in science and innovation is not merely a matter of representation but has significant implications for the quality and inclusiveness of research outcomes. Diverse leadership teams have been shown to enhance creativity, improve problem-solving, and foster more comprehensive and socially responsive innovations. The absence of women in leadership roles can therefore result in a narrow range of perspectives, potentially limiting the scope and impact of scientific and technological advancements. This is particularly relevant in addressing complex global challenges such as climate change, public health, and digital transformation, where inclusive and multidisciplinary approaches are essential.

Another important dimension of this issue relates to socio-cultural norms and gendered expectations that influence women's career trajectories. Traditional perceptions of leadership as a predominantly male domain, combined with expectations related to family responsibilities and work-life balance, often discourage women from pursuing or sustaining leadership roles. In addition, the lack of visible female role models in science and innovation further reinforces the perception that leadership in these fields is not equally accessible to women. These factors collectively contribute to a "leaky pipeline," where women gradually exit or stagnate at different stages of their academic and professional careers.

The institutional environment also plays a critical role in shaping leadership opportunities. Organizational cultures that lack inclusivity, transparency, and gender-sensitive policies can hinder women's advancement. Issues such as implicit bias in hiring and promotion processes, unequal distribution of resources, and limited access to mentorship and sponsorship opportunities further exacerbate the gender gap in leadership. As a result, even highly qualified and capable women may face disproportionate challenges in achieving leadership positions within scientific and innovation ecosystems.

Given the increasing importance of innovation in driving economic growth and addressing global challenges, enhancing women's leadership in science and innovation has become a strategic priority for governments, institutions, and international organizations. Promoting gender equality in

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leadership is not only a matter of social justice but also a key factor in strengthening innovation capacity and ensuring sustainable development. Inclusive leadership can lead to more diverse research agendas, improved organizational performance, and more equitable distribution of opportunities within the scientific community.

This paper aims to examine the key barriers limiting women's leadership in science and innovation and to analyze the broader implications of this gap for innovation systems. It further seeks to identify effective strategies and policy interventions that can support women's advancement into leadership roles. By adopting a multidisciplinary perspective, the study contributes to the growing body of research on gender equality in STEM and provides practical recommendations for fostering more inclusive and resilient innovation ecosystems.

This study adopts a qualitative, analytical, and interdisciplinary research design to examine the factors influencing women's leadership in science and innovation. Given the complexity of leadership dynamics and gender disparities, the research integrates perspectives from gender studies, organizational theory, innovation studies, and higher education research.

2. Materials and methods

The primary methodological approach is a systematic and critical review of existing literature. Academic journal articles, international reports, and policy documents published by leading organizations such as UNESCO, the World Economic Forum, and the OECD are used as the main data sources. These materials were selected based on their relevance, credibility, and recency, with particular emphasis on studies addressing gender equality, leadership representation, and innovation systems. The literature review focuses on identifying recurring patterns, structural barriers, and enabling factors that shape women's access to leadership roles in scientific and technological domains.

In addition, the study employs a comparative analytical method to explore differences in leadership trajectories between men and women within STEM and innovation environments. This approach allows for the examination of disparities in career progression, access to resources, and participation in decision-making processes. Key variables considered include institutional support, availability of mentorship and sponsorship, organizational culture, and access to professional networks. The concept of the "glass ceiling" is used as a theoretical framework to interpret invisible barriers that limit women's advancement to senior and executive positions.

Furthermore, elements of qualitative discourse analysis are incorporated to investigate how leadership is constructed and represented in academic, institutional, and media contexts. This includes analyzing how language, narratives, and communication practices may implicitly reinforce gendered perceptions of leadership as a male-dominated domain. Such analysis helps to uncover subtle biases that influence both self-perception among women and evaluation processes within organizations.

The study relies on secondary data sources, including statistical indicators on gender representation in leadership positions, research funding distribution, and publication patterns. These data are used to support the analytical findings and provide a broader empirical context. While the use of secondary data allows for a comprehensive and global perspective, the study acknowledges limitations related to data consistency and the absence of primary empirical investigation.

To ensure validity and analytical depth, the research applies a triangulation approach, combining insights from multiple sources and methodologies. This enables a more nuanced understanding of the issue and strengthens the reliability of the conclusions drawn.

Overall, the methodological framework provides a robust basis for analyzing the structural, cultural, and institutional dimensions of women's leadership in science and innovation. It supports the identification of key challenges and informs the development of evidence-based recommendations aimed at fostering inclusive leadership and enhancing women's participation in decision-making processes within innovation ecosystems.

The findings of this study indicate that women's underrepresentation in leadership positions within science and innovation is a persistent and multifaceted issue shaped by structural, institutional, and socio-cultural factors. Despite progress in women's access to higher education and participation in STEM fields, their advancement into senior and decision-making roles remains significantly limited. This disparity highlights a critical gap between participation and leadership, suggesting that access alone is insufficient to ensure equality in outcomes.

One of the key findings relates to the existence of structural barriers commonly described as the "glass ceiling." Women often encounter invisible yet powerful constraints that limit their progression to leadership positions, even when they possess comparable qualifications and experience to their male counterparts. These barriers manifest in unequal access to research funding, limited representation in high-impact publications, and underrepresentation in senior academic and managerial roles. As a result, women are less likely to influence strategic decision-making processes within scientific and innovation systems.

Another important finding concerns the role of organizational culture and institutional practices. The analysis shows that many scientific and research institutions continue to operate within traditionally male-dominated frameworks, where leadership traits are implicitly associated with masculine characteristics such as assertiveness and competitiveness. This bias can disadvantage women, whose leadership styles may differ but are equally effective. Additionally, implicit bias in recruitment, promotion, and evaluation processes further exacerbates gender disparities. Women are often subject to higher performance expectations while receiving less recognition for their achievements, which slows their career advancement.

The study also highlights the critical importance of mentorship, sponsorship, and professional networks in shaping leadership trajectories. Access to influential networks and senior mentors is a key factor in career progression; however, women frequently have limited access to these resources. The absence of strong support systems reduces opportunities for skill development, visibility, and leadership positioning. Conversely, evidence

suggests that targeted mentorship programs and inclusive professional networks can significantly enhance women's leadership potential and career outcomes.

A further dimension of the findings relates to the role of socio-cultural norms and gendered expectations. Traditional perceptions of gender roles continue to influence career choices and professional aspirations. Women often face additional pressures related to balancing professional responsibilities with family and caregiving roles, which can limit their availability for leadership positions that demand high levels of time commitment and mobility. These challenges contribute to the "leaky pipeline" phenomenon, where women gradually exit or stagnate at different stages of their careers, particularly at mid-career and leadership transition points.

In addition, the analysis underscores the influence of discourse and representation in shaping leadership opportunities. Leadership in science and innovation is often portrayed through narratives that emphasize male dominance, thereby reinforcing stereotypes about who is suited for leadership roles. The lack of visible female leaders in academic publications, institutional leadership, and media representations further perpetuates this cycle. This not only affects external perceptions but also impacts women's self-confidence and willingness to pursue leadership positions.

The implications of these findings are significant for innovation systems and organizational performance. The underrepresentation of women in leadership limits diversity in decision-making, which is essential for creativity, problem-solving, and the development of inclusive innovations. Research consistently shows that diverse leadership teams produce more effective and sustainable outcomes. Therefore, failing to promote women's leadership represents not only a social inequity but also a missed opportunity for enhancing innovation capacity and competitiveness.

In response to these challenges, the study identifies several strategic recommendations. First, institutions must implement transparent and equitable recruitment and promotion processes that actively address implicit bias. Second, leadership development programs specifically designed for women can help build the necessary skills, confidence, and networks required for advancement. Third, mentorship and sponsorship initiatives should be institutionalized to provide women with sustained support throughout their careers.

Fourth, organizational cultures must evolve to become more inclusive and supportive of diverse leadership styles. This includes recognizing and valuing different approaches to leadership, as well as promoting work-life balance through flexible policies and supportive workplace practices. Fifth, increasing the visibility of successful women leaders in science and innovation is crucial for challenging stereotypes and inspiring future generations. This can be achieved through media representation, academic recognition, and institutional acknowledgment.

Finally, policy-level interventions play a critical role in driving systemic change. Governments and international organizations should promote gender equality through targeted funding programs, leadership quotas where appropriate, and initiatives that support women's participation in high-level decision-making. Such measures can accelerate progress and create a more balanced and inclusive innovation ecosystem.

3. Conclusion

Overall, the results demonstrate that enhancing women's leadership in science and innovation requires a comprehensive and coordinated approach that addresses structural, cultural, and institutional barriers. By fostering inclusive environments and providing targeted support, it is possible to unlock the full potential of women as leaders, thereby strengthening innovation systems and contributing to sustainable development.

This study has explored the persistent gender gap in leadership within science and innovation, emphasizing that women's underrepresentation is not merely an issue of participation but a reflection of deeper structural, institutional, and socio-cultural inequalities. The findings demonstrate that despite increased access to education and growing involvement in STEM fields, women continue to face significant barriers in advancing to leadership and decision-making positions. These barriers, including the "glass ceiling," implicit bias, limited access to networks, and unequal distribution of opportunities, collectively restrict women's professional growth and influence within innovation ecosystems.

The analysis further reveals that the absence of women in leadership roles has broader implications beyond individual career outcomes. It limits diversity in perspectives, reduces the inclusiveness of research agendas, and constrains the overall effectiveness of innovation systems. In an era where complex global challenges require interdisciplinary and inclusive solutions, the lack of gender diversity in leadership positions represents a critical gap in the capacity of scientific and technological development.

Importantly, the study highlights that addressing this issue requires more than increasing numerical representation. It calls for a fundamental transformation of institutional cultures, leadership models, and evaluation systems. Creating inclusive environments where diverse leadership styles are recognized and valued is essential for enabling women to thrive. Moreover, strengthening mentorship structures, expanding access to professional networks, and ensuring transparency in recruitment and promotion processes are key to supporting women's advancement.

Policy interventions also play a decisive role in accelerating progress. Targeted initiatives such as leadership development programs, gender-responsive funding mechanisms, and institutional accountability measures can significantly enhance women's representation in senior positions. At the same time, promoting work-life balance and flexible career pathways is essential to addressing the structural constraints that disproportionately affect women.

In conclusion, enhancing women's leadership in science and innovation is both a matter of equity and a strategic necessity. Empowering women to take on leadership roles not only promotes fairness but also strengthens innovation capacity, improves decision-making quality, and contributes to more sustainable and inclusive development. Achieving this goal requires coordinated efforts across educational institutions, research organizations, and policy frameworks.

Only through such comprehensive and sustained actions can the full potential of women as leaders in science and innovation be realized, ultimately benefiting society as a whole.

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Research on the synthesis of zeolite NaX using Angren kaolin

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Abstract: In this study, the potential use of Angren kaolin as a source of silicon and aluminum oxides for the synthesis of NaX zeolite was investigated. The synthesis of NaX zeolite involved several stages: obtaining metakaolin from kaolin, preparing the synthesis mixture with the required molar ratio of the initial components, adding silicate to regulate the Si/Al ratio in accordance with X-type zeolites, and subsequent hydrothermal treatment at 120 °C. X-ray diffraction (XRD) analysis confirmed the successful transformation of the synthesized mixture into NaX zeolite. Spectroscopic analyses further verified the formation of the crystalline structure of NaX zeolite synthesized using kaolin as a source of silicon and aluminum.

Keywords: kaolin, porous materials, zeolite NaX, spectroscopy, hydrothermal method, crystal

1. Introduction

Zeolites are typically synthesized from kaolin (a source of Si and Al), mixtures of sodium silicate and aluminate [1], as well as from natural mineral sources [2]. To activate kaolin and enhance its reactivity, it is subjected to thermal treatment in the range of 500–800 °C, leading to the formation of metakaolin. The resulting amorphous metakaolin is then treated with alkaline metal hydroxide solutions of appropriate concentration, usually at temperatures up to 100 °C. The micropore size of the synthesized zeolites depends on the composition of the reaction mixture. When uncalcined kaolin is used in the synthesis process, it tends to transform into feldspar or hydrosodalite under the influence of NaOH solution. Structural variations in synthetic zeolites of types A, P, X, and Y are primarily determined by their aluminum (aluminum oxide) content. These differences affect both the crystalline framework of the zeolite and its selectivity in ion-exchange processes. Furthermore, higher aluminum and sodium contents increase the ion-exchange capacity and dissolution rate of the zeolites.

The synthesis of NaX zeolite from kaolin [3], as well as compounds that include mixtures of other metal oxides [4-5], and silicate and aluminate mixtures containing SiO_2 and Al_2O_3, is aimed at obtaining these compounds through synthesis. The synthesis of NaX zeolite from natural kaolin provides an effective approach to the rational use of natural resources. The synthesis of NaX zeolite from kaolin refers to the reaction between minerals and sodium aluminosilicates, resulting in the formation of Na-X type zeolite. In this process, natural aluminosilicates from kaolin undergo chemical changes to yield zeolite with high surface area and adsorption properties. NaX zeolite, in particular, is used in various industries for gas and liquid filtration, ion exchange, and as a catalyst carrier [6].

NaX zeolite has a cubic crystal system, which provides a structure with a high degree of symmetry and more complex structural arrangements. The NaX zeolite consists of the linkage of silicate (SiO_4) and aluminate (AlO_4) tetrahedra, which forms a "3D" network. In NaX zeolite, sodium (Na^+) ions are positioned within the crystal structure, primarily to balance the charge of the aluminum and silicate tetrahedra. The Na^+ ions contribute to the high porosity and act as carriers, providing NaX zeolite with its high adsorption and ion-exchange properties [7].Its chemical formula is $Na_2O{\bullet}Al_2O_3{\bullet}nSiO_2{\bullet}xH_2O$, where zeolites with an (n) value of 2–3 are categorized as zeolite X, while those with higher (n) values fall under zeolite Y [8–9].

Kaolin, with a Si/Al ratio near 1, is an optimal precursor for synthesizing low-silicon zeolites. While significant research has focused on producing zeolite NaA from kaolin [10–11], investigations into kaolin-derived zeolite NaX remain highly pertinent. To crystallize zeolite NaX, the Si/Al ratio in the reaction mixture must exceed 1, typically achieved by introducing additional silica from external sources [12–13]. Notably, impurities such as quartz and mica in kaolin have minimal impact on its transformation into metakaolin or the subsequent synthesis of zeolite NaX [14].

The synthesis process begins with the purification of kaolin to remove impurities that could hinder the reaction. Organic acids have been identified as effective agents for eliminating iron compounds. Previous studies have also examined the synthesis of NaX zeolites using kaolin in fluoride-rich environments [15]. The production of silicon-based zeolites from kaolin typically involves two main steps: (1) the thermal activation of kaolin to convert it into metakaolin through dehydroxylation, and (2) the hydrothermal reaction of metakaolin with an alkaline solution in an aqueous medium. Research has highlighted the critical role of the metakaolinization temperature in influencing the yield of NaX zeolite, demonstrating its significant impact. Moreover, approaches to incorporate additional SiO_2 sources during NaX synthesis have been investigated [16].

This study explored the potential of using kaolin as an alternative source of silica and alumina for the hydrothermal synthesis of zeolite NaX. To achieve the appropriate Si/Al

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ratio required for zeolite NaX crystallization, external silicate sources were added to the mixture. The synthesized NaX zeolite was characterized through XRD and FTIR analyses, with detailed assessments of its crystalline morphology, framework structure, and pore volume.

2. Materials and methods

In this study, AKF-78 grade Angren kaolin, comprising 31.2% Al_2O_3, 48.4% SiO_2, 1.34% Fe_2O_3, and 1.18% MgO, served as the aluminosilicate source. Sodium hydroxide (99% NaOH) and sodium silicate (99% Na_2SiO_3) were utilized during the synthesis process. Oxalic acid was applied for chemical treatment to eliminate Fe^{2+} ions, while distilled water was used for washing and removing residual chemicals during purification.

Synthesis of zeolite NaX

The kaolin sample was ground using a specialized mill to achieve a particle size of 100 nm. The conversion of kaolin to metakaolin was performedby heating the sample to 650°C. The milled sample was treated with a 0.5 M oxalic acid ($C_2H_2O_4$) solution at 100°C, cooled to room temperature, and subsequently filtered. The filtered material was then dried. To prepare a mixture with a molar ratio of Si/Al =2 and Na/Si=1:1, metakaolin, NaOH, and liquid glass were taken in appropriate amounts. The resulting mixture was processed at 100°C with continuous stirring using a magnetic stirrer. The prepared sample was transferred to an autoclave and subjected to hydrothermal treatment at 120°C for 24 hours. The sample is washed with distilled water, filtered, and dried overnight (Figure 1).

Characterization of synthesized zeolite NaX

The chemical composition of the kaolin used for synthesis was determined by X-ray fluorescence (XRF). The obtained NaX zeolite and kaolin crystal phases were analyzed using X-ray diffraction (XRD) and infrared spectrometry methods (SHIMADZU XRD-6100 and ALPHA II FT-IR).

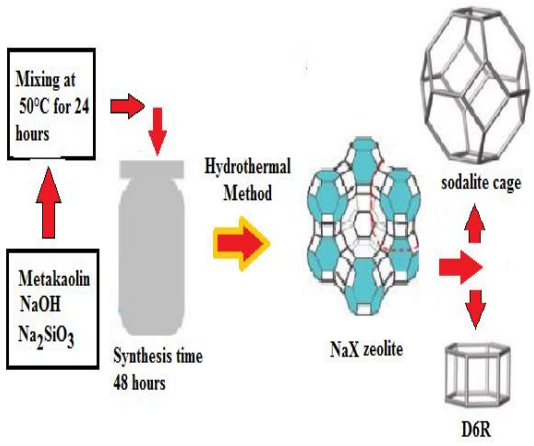

Fig. 1. Method of synthesis of NaX zeolite by hydrothermal method

The composition of kaolin treated with an organic acid solution contains SiO_2 and Al_2O_3 oxides, with small amounts of metal oxides remaining (Table 1). The low concentrations of metal oxides in the purified kaolin do not interfere with the synthesis of NaX zeolite. The chemical composition of the obtained NaX zeolite mainly consists of silicon and oxygen, with sodium acting as a stabilizing cation (Figure 2). During the synthesis process, kaolin dissolves in a NaOH solution and is washed with distilled water in the final stage. It is then calcined at a temperature of 800 °C.

Table 1

Purified Angren kaolin composition

Material	Al_2O_3	Na_2O	SiO_2	Fe_3O_4	K_2O	Other
%	37.4	5.5	55.6	0.1	0.2	1.3

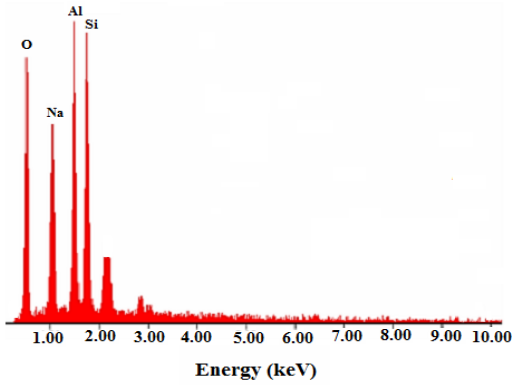

Fig. 2. Elemental composition of NaX zeolite

In the synthesis of zeolites, the synthesis conditions, the purity of the reagents, temperature, and the crystallinity of the obtained product play a crucial role. Crystallization time is significant in thehydrothermal synthesis method, and it is necessary to optimize the crystallization time and temperature duringthe process. The molar ratioof the synthesis products affects the surface area and structure of NaX zeolite.

Temperature is a crucial parameter in the nucleation and crystallization of zeolites synthesized via the hydrothermal method. In zeolite synthesis, high temperatures increase thermal energy and reduce crystallization time. Primarily, zeolite formation occurs more effectively at elevated temperatures. In this study, the crystallization temperature for synthesizing NaX zeolite from processed Agren kaolin was set at 120°C. Several analyses were conducted on the morphological structure and crystallization of the synthesized zeolite.

NaX zeolite synthesized from Angren kaolin via the hydrothermal method, along with Linde NaA zeolite and kaolin samples, were analyzed using X-ray diffraction (XRD) with a SHIMADZU XRD-6100 diffractometer. The XRD data from these samples revealed several distinct diffraction peaks (Fig. 3).

The crystal structure of NaX zeolite is distinctive, and its diffraction peaks are clearly visible in the XRD analysis. The XRD pattern of NaX zeolite exhibits the following characteristics: NaX zeolite has a Faujasite (X) crystal structure, which generates distinct diffraction peaks at 6.08°, 9.94°, 23.27°, 26.61°, and 31.98° in the XRD diagram. These peaks reflect the crystal structure of the aluminosilicate network of NaX zeolite. XRD analysis is crucial in determining the degree of crystallinity of the synthesized NaX zeolite, as the intensity of the peaks identified in the diagram indicates the crystallization degree. Higher peaks

correspond to more crystallized NaX zeolite, while lower peaks indicate amorphous or semi-crystalline material. Secondary phases, such as NaY or amorphous silica, may also emerge during the synthesis process. These phases can form distinct peaks in the XRD diagram. Such phases indicate the efficiency of the synthesis process and the complete utilization of the raw materials. In the XRD spectrum of the processed kaolin, two low-intensity peaks at 12.05° and 24.74° can be observed. This situation is explained by the incomplete dissolution of kaolin in the NaOH solution[19].

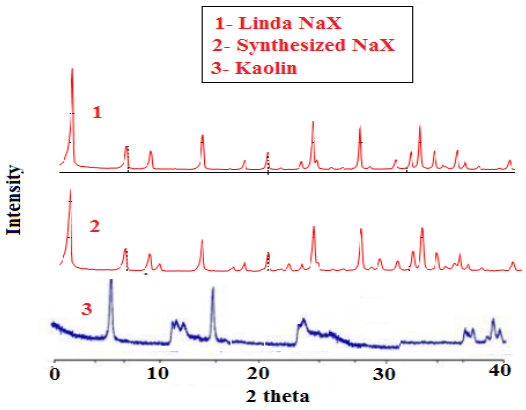

Fig. 3. XRD image of kaolin, Linda NaX, synthesized NaX zeolite crystals

The infrared (IR) transmissivity of kaolin and NaX zeolite synthesized from silicates was analyzed in the study. Analyzing the IR absorption and transmissivity of NaX zeolite helps in understanding its chemical structure, phase properties, and changes. NaX zeolite, with its crystalline and amorphous structures, high porosity, and molecular adsorption characteristics, can be studied using infrared (IR) spectroscopy. The IR spectrum of NaX zeolite reveals the structure of the zeolite and the bonding in its composition, reflecting the connections between silica (SiO_2) and aluminum oxide (Al_2O_3) units in its crystalline structure (Figure 4).

In the IR spectrum of kaolin, peaks related to tetrahedral Si-O and Al-O units were observed at 1108 cm^{-1}, and Si-O bond-related peaks were observed at 1028 cm^{-1}. In the IR spectrum of NaX zeolite, there is no Al-O-H vibration at 914 cm^{-1}. The peak at 756.43 cm^{-1} indicates the symmetric Si-O-Si vibration. NaX zeolite contains silica (SiO_4) tetrahedra, and the Si-O bonds show strong absorption in the IR spectrum around 1000-1200 cm^{-1}. The peaks around 400-600 cm^{-1} originate from the crystalline structure of aluminum oxide. Anothercharacteristicvibrationwas detected at 564.56 cm^{-1}, indicating the presence ofsecondary six-membered rings (D6R), which aretypicalfor the X-type zeolite structure.

NaX zeolite also contains unbonded hydroxyl (OH) groups, which exhibit broad absorption peaks around 3600-3700 cm^{-1}. These hydroxyl groups appear after the zeolite washing or adsorption of water. In the sample, the vibration at 3452.22 cm^{-1} corresponds to hydroxyl (OH) groups, while the peak at 1640.55 cm^{-1} indicates the presence of water molecules. The IR spectrum analysis of NaX zeolite aids in understanding its structure and chemical properties, providing valuable information about Si-O and Al-O bonding as well as OH groups. The zeolite's ion-exchange properties and its conductivity characteristics during gas/liquid adsorption processes are also defined by these interactions.

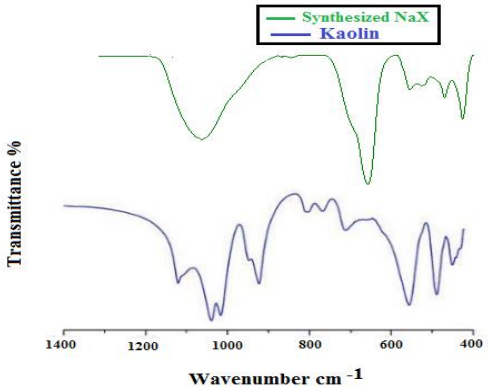

Fig. 4. FTIR spectra of synthesized NaX zeolite and kaolin

These spectroscopic findings confirm that the NaX zeolite, synthesized using kaolin as a silicon and aluminum source, successfully formed a crystalline structure.

3. Conclusion

In this study, the potential use of Angren kaolin as a source of silicon and aluminum oxides for the synthesis of NaX zeolite was investigated. The synthesis of NaX zeolite involved the following stages: obtaining metakaolin from kaolin, preparing the synthesis mixture with the required molar ratio of the initial components, adding silicate to regulate the Si/Al ratio in accordance with X-type zeolites, and subsequent hydrothermal treatment at 120 °C. X-ray diffraction (XRD) analysis confirmed the successful transformation of the synthesized mixture into NaX zeolite. Spectroscopic analyses verified the successful formation of the crystalline structure of NaX zeolite synthesized using kaolin as a source of silicon and aluminum.

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Neuropedagogical strategies for teaching foreign languages to preschool children within the framework of the "Ilk qadam" state program and digital transformation in Uzbekistan

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Abstract: This research paper provides a comprehensive analysis of the neurophysiological foundations of foreign language acquisition in the preschool education system. Within the framework of the "Ilk Qadam" state curriculum, the effectiveness of neuropedagogical approaches is explored, specifically focusing on the relationship between brain plasticity and cognitive development. The article scientifically substantiates the role of digital technologies and interactive musical tools in the process of linguistic coding. The research findings indicate the necessity of implementing an educational model based on multisensory integration and neurobiological principles to enhance the intellectual potential of preschool children.

Keywords: neuropedagogics, preschool education, language acquisition, cognitive development, digital integration, ilk qadam program, sensory integration

1. Introduction

The contemporary educational policy of the Republic of Uzbekistan particularly the systemic reforms in the preschool sector serves as a fundamental basis for human capital development within the framework of the New Uzbekistan strategy Research conducted at prestigious institutions such as the Jizzakh State Pedagogical University named after Abdulla Qodiriy demonstrates that the intellectual development of preschool children is directly linked to their cognitive ability to acquire foreign languages from an early age The "Ilk Qadam" state curriculum has created the necessary structural and methodical base to organize this process systematically providing a unified approach to early childhood development However to raise the quality of education to international standards and ensure global competitiveness it has become a modern requirement to move away from traditional pedagogical rote learning and integrate innovative fields such as neuropedagogics which focuses on the brain-based mechanisms of learning The relevance of this research lies in its illumination of the complex links between brain activity and linguistic acquisition from a neurophysiological perspective suggesting that teaching methods must align with the natural biological rhythms of the developing mind. According to neuropedagogical theory childhood especially the stage from three to seven years old is characterized by the rapid formation of new synaptic connections between brain neurons which forms the tructural foundation for all future learning During this critical period brain plasticity reaches its peak and the young brain receives any external information particularly linguistic sounds and phonetic structures with extreme sensitivity and high retention levels The implementation of digital transformation in the educational isnstitutions of the Jizzakh region is creating unprecedented technological opportunities to accelerate these natural biological processes by providing interactive and multisensory stimuli The integration of a digital environment with neuropedagogical principles allows for the creation of an immersive language learning experience that mimics the natural acquisition of a mother tongue The goal of our research is to determine to what extent the effectiveness of foreign language learning in children can be increased by harmonizing these neuropedagogical principles with the digital tools available in modern preschools. Furthermore the cognitive development of preschool children is fundamentally dependent on their verbal activity and the synchronized functioning of both brain hemispheres which is best stimulated through engaging and non-stressful educational environments Neuropedagogics emphasizes the importance of the emotional state in learning suggesting that the activation of the brain's dopamine system through gamified digital technologies significantly enhances long-term memory consolidation In the digital learning space the strategic distribution of visual and auditory stimuli based on neurophysiological limits prevents intellectual fatigue and ensures that linguistic information is processed efficiently Experiments conducted by researchers at the Jizzakh State Pedagogical University confirm that the interactive capabilities of digital platforms act as the most effective catalyst for stimulating interneuronal connections during language exercises Consequently this research aims to establish a new generation of language teaching methodology that bridges the gap between sophisticated technology and the natural cognitive potential of the human brain ensuring a high-quality educational outcome for the future generation of Uzbekistan.

2. Materials and methods

In the preparation of this scientific work qualitative and quantitative analysis methods were utilized effectively to ensure a holistic understanding of the learning processes within the preschool environment The research process was meticulously organized at the specialized pedagogical laboratories of Jizzakh State Pedagogical University named after Abdulla Qodiriy in close collaboration with local preschool education organizations across the Jizzakh region international standard was chosen as the structural basis of the methodology ensuring the consistency and academic accuracy of the research while aligning with global scientific

publication requirements In the initial stage the content and pedagogical essence of the "Ilk Qadam" state curriculum were analyzed in comparison with modern neurolinguistic research to identify points of convergence between national standards and brain based learning theories.Subsequently a structured experimental framework was established where the educational process was built entirely on the principles of Brain Based Learning focusing on the neurophysiological needs of the developing child The children participating in the study were strategically divided into three main groups to observe the impact of different pedagogical stimuli In the first group education was conducted through traditional textbooks and classical repetition methods serving as the control group for the study In the second group a specialized neuropedagogical approach namely sensory integration methods was applied where physical movement and tactile experiences were linked to linguistic input In the third and most innovative group neuropedagogical methods were harmonized with digital "smart" technologies including interactive boards and mobile learning applications designed to stimulate various brain regions simultaneously. During the comprehensive data collection process children's phonetic perception vocabulary acquisition and overall communicative activity were recorded through detailed observation cards and qualitative assessment tools This approach allowed for the tracking of subtle shifts in linguistic behavior that standardized testing might overlook Furthermore the role of interactive music education took a special place in the research because musical rhythm acts as the strongest biological catalyst in stimulating the language centers of the brain specifically the Broca's and Wernicke's areas The research methodology utilized a sophisticated psychological-pedagogical monitoring system that prioritizes the child's mental state and natural interests instead of strict numerical tests or high-pressure assessments This ensured that the data gathered reflected the children's true cognitive potential in a stress free and naturalistic learning environment fostering more accurate results regarding the synergy between digital tools and neurophysiological development.

3. Results and discussion

The results of the experimental research conducted within the specialized pedagogical framework provided conclusive evidence that neuropedagogical stimuli accelerate the linguistic acquisition process several times compared to conventional instruction Especially in the third group where a strategic combination of digital tools and neuropedagogical methods was implemented the level of children's foreign language word retention and conceptual understanding was significantly higher It was determined during the neuro-behavioral observations that the simultaneous presentation of high-quality visual and auditory signals strengthens the functional cooperation between the left and right hemispheres of the brain effectively ensuring the seamless transfer of linguistic information from short-term sensory input to long-term cognitive memory storage While clear signs of cognitive fatigue and diminished engagement appeared much more quickly in children taught by the traditional rote-learning method those in the interactive digital environment demonstrated stable educational motivation and sustained attention concentration until the very end of the instructional session. Furthermore the empirical data showed that teaching foreign languages through digital music and interactive multisensory games significantly lowers the affective filter which refers to the psychological barrier of fear and stress that often inhibits early childhood learning Children in the experimental groups began to accept linguistic mistakes naturally without the characteristic fear of speaking or performing in a new language This psychological liberation allows the Broca's and Wernicke's areas the primary linguistic processing centers of the brain to function freely and without the inhibitory effects of cortisol-induced stress Especially when examining the local conditions of the Jizzakh region it was observed that the phonetic pronunciation and articulatory accuracy of children in kindergartens equipped with modern digital technologies were formed much more precisely than those in a traditional classroom environment The success and scalability of the "Ilk Qadam" state program were scientifically proven to be deeply rooted in such innovative and neurophysiological approaches which align pedagogical practice with the natural developmental trajectory of the human brain.

In the discussion part of our research it is worth noting that teaching foreign languages in the preschool stage is not merely about the mechanical memorization of vocabulary but rather represents a fundamental process of shaping the child's cognitive architecture for lifelong learning Modern neurophysiological data confirms that the developing brain codes and stores information effectively only when the input is both emotionally resonant and logically stimulating for the child From this perspective the methodical recommendations being developed by the scholars and students of Jizzakh State Pedagogical University serve to advance a sophisticated "smart" education model that aligns with global pedagogical trends In the context of rapid digital transformation the traditional role of the pedagogue must undergo a significant shift where the teacher is no longer just a passive information provider but evolves into a neuro-facilitator who deeply understands and responds to the specific neurobiological needs and developmental windows of each child. Moreover during the extensive discussions and analysis of the experimental data a highly innovative suggestion was put forward to integrate national cultural elements as specialized neuropedagogical breaks within the foreign language curriculum This includes the adaptation of physical balance elements from the traditional Uzbek art of "Darbozlik" or the rhythmic structures of our classical music as kinesthetic and auditory transitions during language lessons Such an approach harmonizes the child's national identity with their global linguistic aspirations ensuring that the acquisition of a new language does not occur in a cultural vacuum but is supported by the familiar neural pathways of their own heritage By utilizing these cultural anchors as a form of sensory "brain break" the teacher can reset the child's attention span and lower cognitive load while simultaneously reinforcing the motor and auditory centers of the brain This synthesis of ancestral wisdom and cutting-edge neuroscience creates a unique Uzbek model of neuropedagogics that is both technologically advanced and culturally grounded providing a sustainable path for the

intellectual advancement of the younger generation in the Jizzakh region and beyond**.**

4. Conclusion

In conclusion, the neuropedagogical foundations of teaching foreign languages to preschool children represent a radically new and effective direction for the education system of Uzbekistan. The conducted analyses have shown that an educational process organized in harmony with the child's developing brain yields results higher than expected. The mutual integration of digital transformation and the "Ilk Qadam" state program serves to increase not only linguistic competencies but also the general intellectual potential of children. These scientific investigations conducted on the basis of Jizzakh State Pedagogical University will undoubtedly serve as an important methodical support in modernizing preschool education. The ultimate goal is to raise each child as a mature and competitive individual of the future, taking into account their individual neurobiological characteristics.

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The role and importance of transport corridors in Uzbekistan

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Abstract: This article provides information on the transport corridors that have passed through the territory of Uzbekistan and are now planned for construction. It studies the strategic importance of international railway corridors passing through Uzbekistan, in particular, with a focus on the China-Kyrgyzstan-Uzbekistan (CKU) railway and its associated multimodal transport routes. The study identifies the role of these corridors in strengthening regional connectivity, reducing transport costs, and strengthening Uzbekistan's position as a transit hub.

Keywords: transport corridors, Uzbekistan, international railway corridors, China-Kyrgyzstan-Uzbekistan railway, Trans-Afghan corridor, regional connectivity, transit potential, logistics hub, freight transportation, eurasian transport network

1. Introduction

Globalization has increased the need for efficient transport systems, in particular, international railway corridors connecting landlocked regions with global markets. Uzbekistan, due to its central location in Central Asia, plays an important role in the development of transcontinental transport networks.

Transport corridors are complex transport routes connecting territories, countries or regions, aimed at efficient freight and passenger transportation, and their role in the transport sector is very important. Transport corridors include the following tasks:

- Ensuring the uninterrupted movement of freight and passengers
- Effective management of transit flows
- Reducing freight transportation time
- Optimizing the flow of wagons and locomotives
- Creating favorable conditions for the formation of interstate trade routes
- Increasing the volume of exports and imports
- Increasing the transit potential of the state
- Strengthening regional influence

Today, transportation is established through Uzbekistan through the following international corridors:

Corridor 1 - ports of the Baltic states (in transit through Kazakhstan and Russia) - in the direction of the ports of Klaipeda (Lithuania), Riga, Liepaja, Ventspils (Latvia), Tallinn (Estonia);

Corridor 2 – in the direction of the European Union countries, through Belarus and Ukraine (in transit through Kazakhstan and Russia) – the border points of Chop (Ukraine) and Brest (Belarus);

Corridor 3 – with access to the Black Sea to the Ukrainian port of Ilyichevsk (in transit through Kazakhstan and Russia);

Corridor 4 – with access to the Black Sea (in transit through Turkmenistan, Kazakhstan and Azerbaijan) in the direction of the Transcaucasian corridor, known as the TRACECA corridor;

Corridor 5 – with access to the Persian Gulf to the Iranian port of Bandar Abbas (in transit through Turkmenistan);

Corridor 6 – to the east through the Kazakhstan-China border crossing (Dostik / Alalshankou) to the eastern ports of China, as well as to the ports of the Far East such as Nakhodka, Vladivostok and others;

Corridor 7 – to Chinese ports with access to the Yellow, East China and South China Seas (in transit through Kyrgyzstan);

Corridor 8 – through the ports of Bandar Abbas, Chahbahar (IRI), Gwadar and Karachi (IRP) of Iran and Pakistan in connection with the solution of the Afghan problem.

2. Materials and methods

Recent initiatives such as the China-Kyrgyzstan-Uzbekistan railway have revived the Silk Road concept and positioned Uzbekistan as a key logistics hub in Eurasia.

This study is based on the following methods:

- qualitative analysis of transport corridor projects
- comparative assessment of regional logistics systems
- synthesis of academic and policy-based sources
- application of a systematic approach to assessing the interaction between infrastructure, economics and geopolitics.

3. Results and discussion

Existing studies emphasize that transport corridors have a significant impact on economic growth and regional integration. Transport corridors increase the transit potential of Uzbekistan.

Our President Sh. Mirziyoyev, at the Shanghai Cooperation Organization summit in Qingdao in June 2018, noted that Uzbekistan supports the construction of the Mazar-i-Sharif-Herat, China-Kyrgyzstan-Uzbekistan railway lines, as well as the development of the Central Asia-Persian Gulf, North-South and East-West trans-regional corridors.

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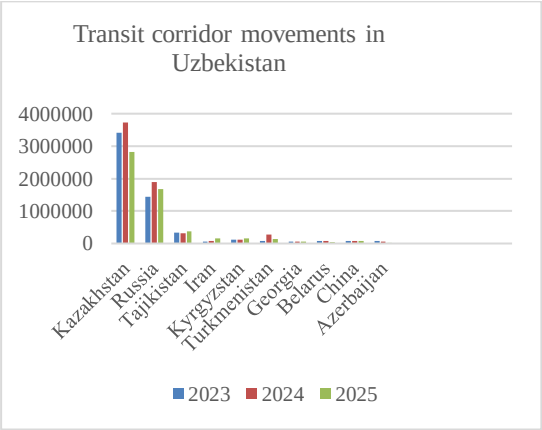

Fig.1. Transit corridor movements in Uzbekistan from 2023 to 2025

Currently, work has begun on the construction of this corridor, which is expected to increase trade competitiveness and stimulate GDP growth through improved logistics efficiency. Moreover, Uzbekistan's participation in these corridors will strengthen its role as a regional transport hub and facilitate integration into global markets.

The China-Kyrgyzstan-Uzbekistan Railway (CKU) is a transport corridor that has been under construction since 2025, and its length is approximately 532 km. If this corridor is operational, it is expected to reduce transit time between China and Europe by 7-10 days.

The Trans-Afghan Corridor will provide access to seaports through Pakistan, transforming Uzbekistan from a landlocked country into a landlocked country.

Fig. 2. TRANSAFGAN corridors

Together, these corridors strengthen Uzbekistan's integration into global supply chains**.**

4. Conclusion

Transport corridors passing through Uzbekistan are of great importance for economic development and regional integration. The country's transport infrastructure can be further developed by studying the existing railway corridors and the newly constructed China-Kyrgyzstan-Uzbekistan and Trans-Afghan highways. This study will help in making strategic decisions in the transport sector and will serve to increase the economic potential of our country. In addition, it will allow diversifying transit routes, reducing dependence on a single transport axis, and strengthening regional cooperation.

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Digital education as a driver for increasing women's participation in STEM fields

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Abstract: Digital education is emerging as a transformative tool for increasing women's participation in STEM (Science, Technology, Engineering, and Mathematics) fields worldwide. Despite recognition of the critical role of women in driving innovation, they continue to face structural barriers, cultural stereotypes, and limited access to high-quality training and mentorship opportunities. This paper explores how online learning platforms, remote training programs, and digital resources can empower women to acquire technical skills, develop leadership capabilities, and actively contribute to innovation ecosystems. Drawing on national initiatives in Uzbekistan, as well as global programs such as "Technovation Girls" and "One Million Programmers," the study highlights the ways in which flexible and accessible digital education promotes creativity, critical thinking, and problem-solving abilities among women. Additionally, the paper examines the socio-psychological and organizational factors that influence women's engagement and persistence in STEM careers, including mentorship networks, supportive policies, and the development of soft skills alongside technical expertise. The findings indicate that digital education not only increases participation and retention of women in STEM but also enhances their capacity to lead innovative projects and drive socio-economic development. By addressing gender disparities through digital learning and inclusive policies, societies can unlock the full potential of women in science and technology, ensuring sustainable innovation and equitable growth.

Keywords: digital Education, women in STEM, gender equality, online learning, STEM education

1. Introduction

Women's participation in STEM (Science, Technology, Engineering, and Mathematics) is essential for advancing innovation, economic growth, and societal development. Despite global efforts to promote gender equality, women still face structural barriers, cultural stereotypes, and limited access to high-quality education and professional opportunities in STEM fields. These challenges are particularly significant in societies where traditional gender norms influence career choices, often steering women toward humanities and social sciences rather than technical disciplines (Smith, 1998).

Digital education has emerged as a transformative tool to bridge these gaps. Online learning platforms, remote training programs, and digital mentorship initiatives provide flexible and accessible pathways for women to acquire technical skills, develop leadership capabilities, and actively contribute to scientific and technological innovation. Programs such as Technovation Girls and One Million Programmers, as well as national initiatives in Uzbekistan, demonstrate that targeted digital interventions foster creativity, critical thinking, and problem-solving abilities among female learners.

Moreover, integrating digital education with mentorship networks, skill development strategies, and supportive policies, including the cultivation of soft skills, enables women to persist and excel in STEM careers. This paper examines how digital education drives women's participation in STEM, highlights best practices, and identifies challenges and opportunities for creating inclusive innovation ecosystems both globally and in Uzbekistan.

Gender disparities in STEM fields remain a global challenge due to cultural, social, and educational barriers. In many countries, girls are more likely to pursue humanities and social sciences rather than science, technology, engineering, and mathematics (STEM) because of societal stereotypes regarding gender roles and career suitability. Digital education provides an opportunity to reduce these barriers by creating accessible, flexible, and inclusive learning environments, thereby encouraging more women to participate in STEM disciplines.

Digital learning platforms, online courses, and e-mentoring programs allow women to access STEM curricula remotely, acquire technical and digital skills in a structured manner, and build networks and mentorship relationships crucial for career advancement. These mechanisms help to mitigate gender bias and enhance social capital, enabling women to thrive in scientific and innovative roles.

Soft skills, including creativity, problem-solving, collaboration, and critical thinking, are increasingly important in digitalized and AI-driven workplaces. Women often demonstrate strong aptitude in these areas, which enhances their potential in fields such as robotics, green technology, and environmental engineering. Digital education supports the development of these competencies and fosters female leadership in STEM.

In Uzbekistan, significant gender gaps persist in higher education. According to international reports, 42% of female graduates work in education, while 45% of male graduates enter STEM fields. Government initiatives, such as the 2030 Higher Education Development Concept, aim to expand STEAM education and support women's participation in

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STEM through scholarships, online courses, and mentoring programs. These policies align with international efforts to promote gender parity and inclusion in STEM education.

International programs such as "One Million Coders" and Technovation Girls provide digital education, mentorship, and innovation competitions. They focus on skill development in coding, robotics, and digital technologies, foster entrepreneurial thinking and problem-solving, and create networking opportunities that increase visibility of female STEM role models. Such programs contribute to retaining women in STEM careers and expanding professional opportunities globally.

2. Materials and methods

This study employs a mixed-methods approach to investigate the impact of digital education on women's participation in STEM fields. The research focuses on identifying the key factors that encourage women to enroll in STEM programs, successfully complete their studies, and pursue STEM-related careers. A combination of quantitative and qualitative methods allows for a comprehensive analysis of both measurable trends and personal experiences, highlighting the barriers, enablers, and best practices in digital learning for women in STEM.

The study is guided by the following research questions, which aim to capture both the individual and systemic dimensions of women's participation in STEM: How does digital education influence women's motivation to pursue STEM studies? This question examines how online courses, e-learning platforms, and virtual workshops affect women's interest in STEM subjects, particularly in environments where traditional classroom access may be limited.

What social, cultural, and institutional factors affect women's engagement in STEM fields? This question explores the influence of societal expectations, gender stereotypes, family support, mentorship opportunities, and institutional policies on women's decision to enter and remain in STEM programs.

How do mentorship, online courses, and skill-building programs contribute to the retention of women in STEM careers? This question focuses on evaluating structured support mechanisms, such as mentoring initiatives, coding clubs, and professional development workshops, and how they help women overcome challenges in STEM education and employment.

What role do soft skills and creativity play in supporting women's success in STEM disciplines? Beyond technical knowledge, this question investigates how interpersonal skills, problem-solving abilities, teamwork, and creative thinking enhance women's performance and career advancement in STEM fields.

The main objectives of this research are as follows:

- To analyze the accessibility and effectiveness of digital education platforms for women in STEM;
- To identify systemic barriers and gender biases that limit women's participation in STEM disciplines;
- To evaluate the impact of mentorship, online training, and skill-building programs on women's confidence, engagement, and persistence in STEM careers;
- To propose practical recommendations for improving policies and programs aimed at increasing women's representation in STEM through digital education.

Digital education has emerged as a critical tool for enhancing gender equality in STEM by providing flexible, accessible, and cost-effective learning opportunities. In many countries, including Uzbekistan, cultural norms and educational structures have historically limited women's participation in STEM. By focusing on digital learning as a driver of empowerment, this study contributes to both academic understanding and practical policy development, offering insights for educators, institutions, and policymakers.

The present study adopts a descriptive, exploratory, and mixed-methods research design, combining both quantitative and qualitative approaches to gain a comprehensive understanding of factors influencing women's participation in STEM fields through digital education. The mixed-methods approach allows the research to not only capture broad trends and patterns across a large population but also explore personal narratives, motivations, and experiences that quantitative methods alone might overlook. This approach ensures triangulation of data, improving the validity and reliability of the research findings.

The study involves 200 female participants from various academic and professional backgrounds in Uzbekistan, selected using stratified purposive sampling to ensure representation across different age groups, STEM disciplines, and levels of education and work experience. The sample consists of:

Undergraduate female students in STEM programs (40%) – these participants provide insights into early exposure to STEM subjects, motivations for choosing STEM, and the role of digital tools in learning.

Graduate female students pursuing advanced STEM degrees (20%) – these participants offer perspectives on higher-level STEM engagement, research challenges, and mentorship experiences.

Professional women currently employed in STEM industries (25%) – these participants provide real-world insights into workforce integration, career progression, and organizational support mechanisms.

Women enrolled in online STEM programs, coding bootcamps, or other digital courses (15%) – this group highlights the impact of digital education in bridging gaps in access, flexibility, and skill development.

To ensure the relevance and reliability of the findings, participants were selected based on the following criteria:

Inclusion: Women actively enrolled in STEM-related academic programs, professionals employed in STEM industries, or participants in online STEM training programs.

Exclusion: Individuals not currently engaged in STEM learning or employment, or those unable to provide informed consent.

Ethical approval was obtained from participating institutions prior to data collection. Participants were fully informed about the purpose of the study, its voluntary nature, and their right to withdraw at any time. Confidentiality and anonymity were ensured through coded identifiers, and all personal information was securely stored. The study adheres

to the principles of respect, beneficence, and justice, ensuring that participants' rights and dignity are fully protected.

The study was conducted in three main phases:

Preparation Phase: Involved designing survey instruments, interview protocols, and focus group discussion guidelines. This phase also included pilot testing the tools with a small sample of participants (n=15) to ensure clarity and reliability.

Main Data Collection Phase: Surveys were distributed online and in-person, interviews were conducted individually, and focus group discussions were held in multiple sessions to ensure participant engagement.

Recommendation Development Phase: Data was analyzed to identify key barriers and opportunities for women in STEM, leading to evidence-based recommendations for educational institutions, policymakers, and digital education providers.

To obtain a comprehensive and multi-dimensional understanding of women's engagement in STEM through digital education, a triangulated data collection approach was employed. The study combines surveys, interviews, focus group discussions, and document analysis.

Surveys were designed to collect quantitative data on participants' access to digital learning platforms, frequency of participation, perceived competency in STEM skills, confidence levels, and barriers to engagement.

Likert-scale questions (ranging from 1 = strongly disagree to 5 = strongly agree) were included to measure self-efficacy, motivation, and attitudes toward STEM education.

Open-ended questions were also included to allow participants to elaborate on challenges, inspirations, and suggestions for improvement.

Conducted with 40 selected participants representing different academic and professional levels.

Interviews aimed to explore personal experiences, mentorship encounters, social and cultural influences, and the role of digital education in developing technical and soft skills.

Each interview lasted between 30 and 60 minutes, and audio recordings were transcribed for thematic analysis.

Eight focus group sessions were organized, each with 6–8 participants.

Discussions encouraged interaction, sharing of common experiences, and identification of systemic barriers and facilitators to women's engagement in STEM.

Topics included gender stereotypes, online learning experiences, peer support, and digital infrastructure challenges.

Institutional reports, national statistics on STEM enrollment, online course analytics, and policy documents were analyzed.

This secondary data provided context for interpreting primary findings and helped identify structural and policy-related factors influencing women's participation in STEM.

Quantitative Analysis: Survey data was analyzed using descriptive statistics (mean, median, standard deviation) and inferential statistics, including correlation and regression analysis, to examine relationships between digital education access and participation in STEM.

Qualitative Analysis: Interview and focus group data were analyzed using thematic analysis, identifying recurring themes such as mentorship, gender bias, social support, and flexibility provided by digital platforms.

Integration of Data: Both qualitative and quantitative findings were integrated to provide a comprehensive understanding of the challenges and opportunities for women in STEM, allowing for triangulated evidence-based recommendations.

The study ensures reliability through pilot testing, standardized survey instruments, and consistent interview protocols. Validity is enhanced by triangulation, cross-verification of data from multiple sources, and peer review of coding and theme identification.

3. Results and discussion

The analysis of collected data aimed to identify both quantitative patterns and qualitative insights regarding the factors that influence women's participation in STEM fields through digital education. The integration of both data types enables a holistic understanding of the complex interplay between personal, institutional, and societal factors.

Survey responses were analyzed using descriptive statistics to determine the central tendencies, variability, and distribution of responses across the sample. Key indicators analyzed included:

Frequency of digital learning engagement: Measures how often participants used online courses, coding platforms, and STEM-related webinars.

Self-reported STEM competency: Assessed participants' confidence in mathematics, programming, engineering, and science-related problem-solving.

Perceived barriers: Identified obstacles such as lack of mentorship, gender bias, time constraints, or limited access to technology.

In addition, inferential statistical methods were employed to explore relationships between variables:

Correlation analysis assessed the strength and direction of associations between digital education engagement and self-perceived STEM competence.

Regression analysis determined the predictive power of factors such as access to digital resources, mentorship programs, and social support on participants' likelihood to persist in STEM fields.

ANOVA (Analysis of Variance) tests examined differences in digital education outcomes across age groups, academic levels, and work experience categories.

The quantitative findings highlighted that consistent engagement with digital education platforms positively correlated with enhanced STEM competencies and higher motivation to pursue STEM careers. Moreover, access to structured online mentorship significantly reduced perceived barriers and increased confidence.

Qualitative data from semi-structured interviews and focus group discussions were analyzed using thematic coding, following Braun and Clarke's six-phase framework (Braun & Clarke, 2006):

Familiarization with data – All transcripts were read multiple times to understand the context and nuances.

Initial coding – Key concepts were identified, including mentorship, gender stereotypes, institutional support, work-life balance, and digital learning flexibility.

Searching for themes – Codes were grouped into broader themes representing recurring patterns across participants' experiences.

Reviewing themes – Themes were cross-verified with multiple coders to ensure consistency and reliability.

Defining and naming themes – Each theme was clearly defined and linked to research objectives.

Reporting – Themes were illustrated with direct quotations from participants to enrich the narrative.

Major qualitative themes identified included:

Mentorship and role models: Participants emphasized that visibility of female mentors in STEM fields significantly boosts motivation and career aspirations.

Digital learning flexibility: Online platforms allow women to balance STEM education with personal and professional responsibilities, particularly for those with family commitments.

Societal and cultural stereotypes: Persistent gender norms influence participants' self-perception and may deter some women from pursuing STEM pathways.

Skill development and creativity: Women reported that digital tools enhance both technical skills and creativity, fostering problem-solving and innovation in STEM projects.

By integrating both quantitative and qualitative insights, the study identifies key enablers and barriers for women in STEM:

Enablers: Access to online courses, supportive mentors, interactive digital tools, flexible learning schedules, and peer networks.

Barriers: Gender biases, insufficient institutional support, societal expectations, and limited exposure to high-quality digital STEM resources.

The triangulation of data ensures that recommendations are evidence-based and address both measurable trends and lived experiences. For instance, statistical findings on improved competency through digital courses are reinforced by participants' narratives emphasizing increased confidence and creativity.

The analysis suggests that digital education acts as a critical driver for increasing women's participation in STEM by offering flexible, accessible, and engaging learning opportunities. However, the full potential of digital tools can only be realized if structural challenges and societal stereotypes are simultaneously addressed.

Educational institutions can enhance women's STEM participation by integrating online mentorship programs, providing tailored digital resources, and promoting collaborative learning environments.

Policymakers can design initiatives to ensure equal access to digital education and support female students and professionals in overcoming systemic barriers.

Industry stakeholders can leverage these insights to create inclusive digital training programs and professional development pathways for women in STEM careers.

In conclusion, the findings demonstrate that a strategic combination of digital education, mentorship, and supportive policies is essential to empower women in STEM, reduce gender gaps, and foster innovation and creativity in scientific and technological fields.

The discussion section synthesizes the key findings from both quantitative and qualitative analyses, providing a comprehensive understanding of the role of digital education in enhancing women's participation in STEM fields. The findings indicate that digital platforms not only improve technical competencies but also empower women psychologically, socially, and professionally. The results highlight several important implications for STEM education. Digital learning platforms reduce geographic and institutional barriers, allowing women from diverse backgrounds to access high-quality STEM resources. This is particularly critical in countries where cultural norms or family responsibilities may limit traditional classroom participation.

Online courses, webinars, and virtual labs provide flexible learning schedules that accommodate personal and professional commitments. Flexibility enables women to pursue STEM education without compromising family or work responsibilities, which is a crucial factor in sustaining engagement.

Digital platforms often incorporate mentorship programs, discussion forums, and collaborative projects, which foster social capital and professional networks. These networks provide women with role models, guidance, and opportunities for career development.

Beyond technical knowledge, digital education encourages the development of critical soft skills such as problem-solving, creativity, communication, and collaboration. As participants reported, these skills are increasingly valued in STEM careers, particularly in innovative and interdisciplinary projects.

The study underscores the persistent gender-specific challenges in STEM:

Stereotypes and societal expectations: Many participants highlighted that cultural norms and traditional expectations influence career choices, often steering women toward humanities or education sectors rather than STEM.

Confidence gaps: Even with access to digital resources, some women reported hesitancy in pursuing STEM-related careers due to self-perceived skill gaps or societal discouragement.

Institutional barriers: Limited institutional support, lack of targeted mentorship, and insufficient recognition of women's achievements in STEM remain barriers that need systemic solutions.

The findings suggest several actionable opportunities:

Institutional strategies: Universities and training providers should design digital curricula tailored to women's needs, integrating mentorship, career guidance, and interactive learning experiences.

Government initiatives: Policies promoting equal access to technology, scholarships for women in STEM, and campaigns challenging gender stereotypes are essential for long-term systemic change. Industry collaboration: Partnerships between educational institutions and industries can provide hands-on experience, internships, and practical projects for women in STEM, ensuring the applicability of digital skills in real-world contexts.

Globally, there is an increasing emphasis on women in STEM, with international organizations such as UNESCO, the International Labour Organization (ILO), and Technovation advocating for inclusive digital learning

strategies. This study aligns with these global initiatives by demonstrating that digital education can serve as a catalyst for addressing gender disparities in STEM participation.

Moreover, the study's findings emphasize that digital education alone is not sufficient; it must be complemented by mentorship, supportive policies, and societal change. Combining these strategies can lead to sustainable increases in women's representation and leadership in STEM, ultimately fostering innovation, creativity, and economic growth.

While the study provides significant insights, several limitations should be noted:

The study primarily relies on self-reported data, which may introduce bias.

Access to digital resources varied among participants, which may affect the generalizability of findings.

Cultural factors specific to Uzbekistan may influence results and may not fully represent experiences in other contexts.

Future research could focus on longitudinal studies to assess the long-term impact of digital education on women's STEM careers, as well as comparative studies across different countries to identify universal and context-specific strategies for increasing women's participation in STEM.

Increasing women's participation in STEM fields requires a comprehensive approach that combines digital education, mentorship, policy support, and societal change. Educational institutions play a crucial role by developing gender-inclusive digital curricula that incorporate both technical and soft skills. Providing mentorship programs and connecting female students with successful role models can boost confidence and motivation, encouraging long-term engagement in STEM careers. Flexible learning options, such as asynchronous online courses, virtual laboratories, and recorded lectures, allow women to balance education with work and family responsibilities. Collaborative projects, hackathons, and problem-solving challenges further enhance practical skills and foster professional networks.

Policymakers also have a critical responsibility in promoting gender equality in STEM. Financial support through scholarships, grants, and stipends targeted at women can increase access to education and reduce dropout rates. Legal frameworks and policies that reduce gender bias ensure equal opportunities in educational and professional settings. Additionally, national campaigns and awareness initiatives can challenge societal stereotypes that discourage women from pursuing STEM, helping to create an environment that values their contributions.

Industry partners can complement these efforts by collaborating with educational institutions to provide internships, practical training, and project-based experiences. Workplace flexibility, such as remote work options and adjustable schedules, makes STEM careers more accessible to women with diverse responsibilities. Establishing inclusive workplace cultures that recognize and reward women's achievements further supports retention and advancement in STEM careers.

International organizations also have a vital role in accelerating women's participation in STEM globally. By supporting digital education programs, facilitating knowledge sharing, and establishing benchmarks for tracking participation, organizations such as UNESCO, ILO, and Technovation can help create effective and culturally adapted strategies. Continuous monitoring and evaluation ensure that progress is measured and policies are adjusted to maximize impact.

In conclusion, increasing women's representation in STEM fields is a multifaceted challenge that requires the combined efforts of educational institutions, policymakers, industry, and international organizations. Digital education serves as a powerful tool to empower women, while mentorship, flexible learning, policy support, and cultural change provide the foundation for sustained engagement and leadership in science, technology, engineering, and mathematics. Implementing these recommendations will contribute to a more inclusive, innovative, and equitable STEM ecosystem worldwide.

4. Conclusion

This study highlights the critical role of digital education in promoting women's participation in STEM fields. Evidence from global and national contexts demonstrates that targeted interventions, including flexible learning options, mentorship programs, and digital skill development, can effectively reduce barriers and enhance women's engagement in science, technology, engineering, and mathematics. Addressing gender disparities in STEM requires a holistic approach that integrates educational strategies, policy frameworks, industry collaboration, and societal awareness.

By implementing gender-inclusive curricula, providing professional development opportunities, and fostering supportive networks, educational institutions can empower women to pursue and sustain STEM careers. Policymakers must create enabling legal and financial environments, while industries should ensure equitable work practices and recognize women's contributions to innovation. International organizations can amplify these efforts by facilitating knowledge exchange, monitoring participation trends, and providing guidance on best practices.

In conclusion, increasing women's representation in STEM is not only a matter of equity but also a driver of innovation, economic growth, and societal progress. A collaborative, multilevel strategy that combines digital education, mentorship, flexible learning, and supportive policies is essential to ensure that women can fully realize their potential in STEM disciplines. Implementing these strategies will contribute to building a more inclusive, diverse, and resilient STEM ecosystem worldwide.

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The effect of dispersed silica gel on the physical and mechanical properties of cement binder for non-autoclaved foam concrete

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Abstract: The effect of ground silica gel on hydration processes, phase composition, and the properties of cement stone as a matrix for non-autoclaved foam concrete was studied. It was established that modification of the binder at a reduced water-cement ratio increases strength by up to 25–30% and improves the structural uniformity of the material. According to the results of X-ray phase analysis (XRD), a decrease in the content of portlandite $Ca(OH)_2$ and an increase in the proportion of the amorphous C–S–H phase were identified, indicating the development of pozzolanic reactions. The obtained data confirm the effectiveness of using ground silica gel for the targeted regulation of the structure and properties of cement stone.

Keywords: ground silica gel, cement stone, cement hydration, X-ray phase analysis, C–S–H phase, water-cement ratio, non-autoclaved foam concrete

Влияние дисперсного силикагеля на физико-механические свойства цементного вяжущего для неавтоклавного пенобетона

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Аннотация: Исследовано влияние измельчённого силикагеля на процессы гидратации, фазовый состав и свойства цементного камня как матрицы неавтоклавного пенобетона. установлено, что модификация вяжущего при пониженном водоцементном отношении обеспечивает повышение прочности до 25–30 % и улучшение структурной однородности материала. по результатам рентгенофазового анализа (рфа) выявлено снижение содержания портландита $ca(oh)_2$ и увеличение доли аморфной c–s–h-фазы, что указывает на развитие пуццолановых реакций. полученные данные подтверждают эффективность применения измельчённого силикагеля для направленного регулирования структуры и свойств цементного камня.

Ключевые слова: измельчённый силикагель, цементный камень, гидратация цемента, рентгенофазовый анализ, C–S–H-фаза, водоцементное отношение, неавтоклавный пенобетон

1. Введение

Неавтоклавный пенобетон ограничен низкой прочностью при пониженной плотности и нестабильностью пористой структуры, что связано с особенностями цементной матрицы. В связи с этим актуальной задачей является её модификация без увеличения плотности материала. Одним из эффективных решений является применение высокодисперсных кремнезёмсодержащих добавок, способных изменять процессы гидратации и структуру цементного камня.

Особый интерес представляют кремнезёмсодержащие материалы аморфной структуры, обладающие высокой реакционной способностью в щелочной среде цементного теста. По данным ряда исследований, такие добавки участвуют в пуццолановых реакциях с гидроксидом кальция, что приводит к снижению содержания портландита и увеличению доли гидросиликатов кальция (C–S–H). Это сопровождается уплотнением структуры цементного камня и повышением его прочностных характеристик [1–3,8].

Дополнительный эффект достигается при использовании поликарбоксилатных суперпластификаторов, позволяющих снижать водоцементное отношение и обеспечивать равномерное распределение дисперсных частиц. В результате формируется более плотная и однородная цементная матрица, что особенно важно для ячеистых бетонов, включая пенобетон [4,5].

В работах, посвящённых модификации пенобетона, показано, что применение микрокремнезёма способствует повышению прочности и стабильности структуры при сохранении низкой плотности материала [6,7]. Однако большинство исследований ограничено традиционными кремнезёмсодержащими добавками, тогда как влияние измельчённого технического силикагеля на процессы гидратации цементного камня и свойства пенобетона изучено недостаточно.

В связи с этим целью настоящей работы является исследование влияния измельчённого силикагеля на гидратацию, фазовый состав и прочностные

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характеристики цементного камня как матрицы неавтоклавного пенобетона.

2. Методология исследования

В качестве основного вяжущего использовали портландцемент класса ЦЕМ II/А-К (3-И) 42,5Н производства АО «Ахангаранцемент».

В роли минеральной модифицирующей добавки применяли технический силикагель китайского производства, поставляемый на территорию Республики Узбекистан компанией *Silsorbent Solutions* (Узбекистан). Перед введением в состав силикагель подвергали механической активации путём помола в лабораторной шаровой мельнице до различной степени дисперсности. На основании серии предварительных экспериментов были установлены оптимальные значения удельной поверхности и содержания добавки.

Оптимальная дозировка измельчённого силикагеля составила 5 % от массы цемента, что обеспечило наиболее благоприятное формирование структуры и повышение прочностных характеристик цементного камня. Удельную поверхность порошка определяли на приборе ПСХ-11А методом воздушной проницаемости (по Блейну); её значение составило 7940 $см^2/г$, что свидетельствует о высокой степени дисперсности и потенциальной пуццолановой активности материала.

В качестве химической модифицирующей добавки использовали поликарбоксилатный суперпластификатор на основе эфиров поликарбоксилатов *Master Glenium* (Германия). Оптимальное содержание добавки, составившее 1 % от массы цемента, было установлено по результатам предварительных экспериментальных исследований.

Для проведения сравнительного анализа были сформированы следующие составы:

- R (контрольный состав) – цементное тесто без добавок (цемент + вода);
- SG5C – цементная композиция с добавлением 5 % измельчённого силикагеля и 1 % суперпластификатора.

Образцы формовали в металлические формы кубической формы размером 20×20×20 мм. После распалубки их выдерживали в условиях нормального твердения при температуре (20 ± 2) °C и относительной влажности воздуха не менее 95 % в соответствии с требованиями ГОСТ 310.4–81 и ГОСТ 10180–2012.

Испытания на сжатие проводили на гидравлическом прессе в возрасте 3, 7 и 28 суток согласно ГОСТ 10180–2012 с регистрацией максимальной разрушающей нагрузки.

Фазовый состав цементного камня исследовали методом рентгенофазового анализа с использованием излучения CuKα в диапазоне углов 2θ = 5–75°. Полученные дифрактограммы подвергали качественной и полуколичественной интерпретации.

3. Результаты исследования

Результаты испытаний прочности при сжатии цементного камня в зависимости от состава и возраста твердения представлены в таблице 1. Анализ полученных данных показывает, что введение измельчённого силикагеля оказывает существенное влияние на В/Ц и формирование прочностных характеристик материала.

Статистический анализ прочностных характеристик выявляет различия в распределении значений и степени их вариабельности в зависимости от состава и возраста твердения, что обусловлено изменением водоцементного отношения и введением химической добавки. Снижение В/Ц с 0,30 до 0,21 достигается за счёт применения поликарбоксилатного суперпластификатора, обеспечивающего эффективное диспергирование цементных частиц и снижение водопотребности системы. На 3 сутки значения прочности сопоставимы, однако вариативность показателей для состава SG5C уменьшается примерно в 2 раза.

К 28 суткам влияние пониженного В/Ц проявляется более отчётливо: прочность модифицированного состава превышает эталон примерно на 25–30 %, при этом коэффициент вариации снижается более чем в 5 раз. Это отражает снижение пористости и повышение однородности цементного камня.

Для эталонного состава R характерно увеличение разброса прочностных показателей с возрастом: коэффициент вариации возрастает более чем в 2 раза к 28 суткам, что свидетельствует о неоднородности.

Таблица 1

Прочность цементного камня контрольного и модифицированного составов в зависимости от возраста твердения

Состав	W/C	Возраст, сут	Прочность при сжатии, МПа (min–max)	Среднее, МПа	Медиана, МПа	SD, МПа	CV, %
R - эталон	0,30	3	45,2 – 71,8	63,4	66,7	10,3	16,3
		7	52,1 – 100,8	74,3	73,0	19,6	26,4
		28	43,0 – 118,5	74,3	73,2	26,7	35,9
SG5C	0,21	3	51,1 – 63,7	59,5	61,0	4,9	8,3
		7	51,4 – 65,8	59,6	57,7	5,8	9,7
		28	87,2 – 101,0	95,4	99,3	6,5	6,8

В отличие от этого, состав SG5C демонстрирует устойчивые статистические характеристики: коэффициент вариации не превышает 10 % на всех стадиях твердения, а снижение стандартного отклонения указывает на высокую воспроизводимость результатов.

С точки зрения прочности, на раннем этапе (3 суток) модифицированный состав демонстрирует сопоставимые или несколько более низкие значения (на 5–7 %) по сравнению с эталоном. Однако к 28 суткам формируется выраженное преимущество: средняя прочность состава SG5C превышает эталон примерно на 25–30 %.

Динамика изменения прочности (рисунок 1) подтверждает различия в характере твердения: для состава SG5C прирост прочности от 3 до 28 суток превышает 60 %, тогда как для эталонного состава он составляет порядка 15–20 %.

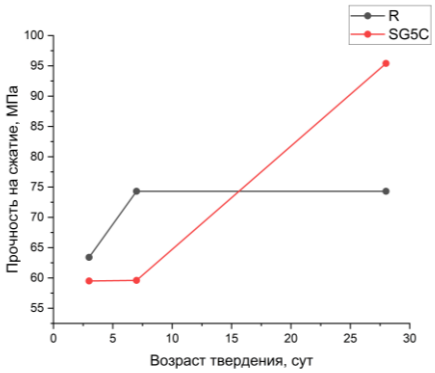

Рис. 1. Динамика прочности цементного камня для эталонного (R) и модифицированного (SG5C) составов

Это указывает на более интенсивное развитие прочности модифицированного состава на поздних стадиях твердения.

Выявленные различия в динамике набора прочности находят отражение в изменении фазового состава цементного камня, что подтверждается результатами рентгенофазового анализа.

На дифрактограммах 3-суточных образцов (рисунок 2) для обоих составов идентифицируются основные продукты гидратации цемента: портландит $Ca(OH)_2$, остаточные клинкерные минералы и аморфная C–S–H-фаза. Дополнительно в низкоугловой области фиксируются отражения сульфоалюминатных гидратов (AFt), характерные для ранней стадии твердения.

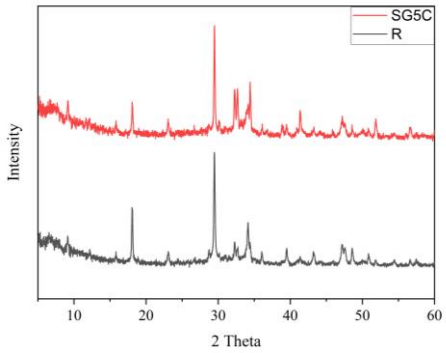

Рис. 2. Рентгенофазовые дифрактограммы цементного камня составов R и SG5C в возрасте 3 суток твердения

При этом для состава SG5C наблюдается менее выраженная интенсивность пиков портландита по сравнению с эталонным составом, а также более заметное аморфное поднятие в области $2\theta \approx 20–35°$, что указывает на более интенсивное формирование C–S–H-геля.

На стадии 7 суток (рисунок 3) для обоих составов формируется более выраженный кристалло-аморфный фазовый состав, отражающий развитие процессов гидратации. На дифрактограммах фиксируются интенсивные рефлексы портландита **$Ca(OH)_2$** ($2\theta \approx 18°$ и 34°), что указывает на его накопление в результате гидратации алитовой фазы. Одновременно сохраняются дифракционные максимумы в области **$2\theta \approx 32–33°$**, относимые к остаточным клинкерным минералам, что свидетельствует о продолжающемся протекании гидратационных процессов.

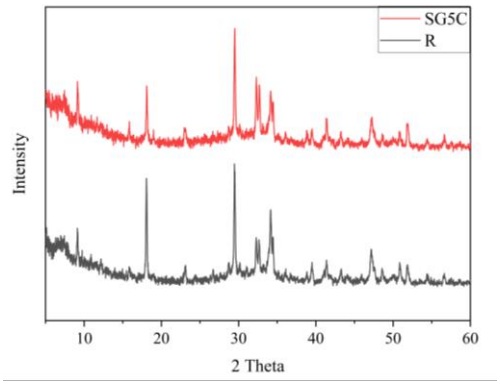

Рис. 3. Рентгенофазовые дифрактограммы цементного камня составов R и SG5C в возрасте 7 суток твердения

В интервале $2\theta \approx 20–35°$ отмечается усиление аморфной составляющей, связанной с увеличением содержания гидросиликатов кальция C–S–H, что отражает развитие структуры цементного камня.

В отличие от эталонного состава, для SG5C характерна меньшая интенсивность портландитовых рефлексов при более выраженной аморфной составляющей, что свидетельствует об изменении соотношения кристаллической и аморфной фаз в системе.

Сопоставление рентгенофазовых данных в возрасте 28 суток (рисунок 4) выявляет различия в характере формирования продуктов гидратации в эталонном и модифицированном составах. Для эталонного цементного камня сохраняется высокая интенсивность отражений портландита $Ca(OH)_2$, что указывает на его накопление как продукта гидратации алитовой фазы.

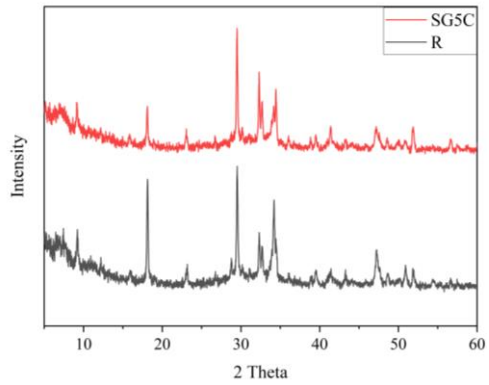

Рис. 4. Рентгенофазовые дифрактограммы цементного камня составов R и SG5C в возрасте 28 суток твердения

В модифицированном составе SG5C наблюдается уменьшение интенсивности портландитовых рефлексов на фоне увеличения доли аморфной составляющей в области $2\theta \approx 20–35°$, связанной с развитием низкокристаллизованных гидросиликатов кальция C–S–H. Это указывает на вовлечение гидроксида кальция во вторичные реакции с кремнезёмсодержащей добавкой.

Снижение содержания $Ca(OH)_2$ и увеличение доли C–S–H-фазы отражают перераспределение продуктов гидратации и сопровождаются уплотнением цементного

камня. Полученные результаты РФА согласуются с данными по прочности: незначительные различия на ранних стадиях твердения и выраженное преимущество модифицированного состава на поздних сроках

4. Заключение

Установлено, что введение измельчённого силикагеля в сочетании с поликарбоксилатным суперпластификатором оказывает комплексное влияние на гидратацию и свойства цементного камня.

Снижение водоцементного отношения с 0,30 до 0,21 приводит к уменьшению капиллярной пористости, что сопровождается повышением прочности и снижением вариабельности показателей.

Модифицированный состав характеризуется более стабильными прочностными характеристиками и ускоренным набором прочности на поздних стадиях твердения.

По данным рентгенофазового анализа установлены снижение содержания портландита $Ca(OH)_2$ и увеличение доли аморфной C–S–H-фазы, что отражает развитие пуццолановых реакций.

Повышение прочности обусловлено совокупным действием снижения В/Ц и образования дополнительной C–S–H-фазы, приводящих к уплотнению цементного камня.

Предложенная модификация перспективна для неавтоклавного пенобетона; вместе с тем требуются дополнительные исследования реологических свойств, порообразования и долговечности.

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Development of Turkic languages in the era of global integration

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Abstract: In the modern world, global integration significantly influences the development of languages. The international status of Turkic languages is gradually increasing, and new stages of their development are emerging. This article examines the historical development of Turkic languages and their role in the process of globalization. It highlights their rich cultural heritage, unique linguistic features, and the importance of digital technologies and the internet in promoting these languages. The study emphasizes that Turkic languages are actively developing and strengthening their position in modern global communication.

Keywords: language family, Turkic language, integration, research.

1. Introduction

In the era of globalization, digital technologies play an important role in the development and preservation of Turkic languages. Today, the use of Turkic languages in online platforms, social networks, and digital media is rapidly increasing. Various mobile applications, online dictionaries, translation tools, and language learning platforms are being created to support these languages.

Moreover, the integration of Turkic languages into artificial intelligence technologies is becoming one of the most important directions of modern linguistic development. Machine translation systems, speech recognition technologies, and natural language processing tools are gradually including Turkic languages in their databases. These technological developments help to increase the accessibility of Turkic languages in the global digital environment and make communication easier for millions of speakers.

Cultural cooperation among Turkic-speaking countries also plays a significant role in strengthening linguistic ties. Joint cultural festivals, academic conferences, and literary forums contribute to the exchange of ideas and experiences among scholars, writers, and researchers. Through these events, the shared cultural heritage of Turkic peoples is preserved and promoted. Translation of literary works from one Turkic language into another is also becoming more common. This process helps people from different Turkic nations better understand each other's traditions, history, and values. As a result, cultural and linguistic integration among Turkic countries becomes stronger.

The future of Turkic languages largely depends on educational development, technological integration, and international cooperation. Expanding Turkic language education in universities, supporting linguistic research, and creating modern educational materials will contribute to the sustainable development of these languages. In addition, the development of joint educational programs among Turkic countries can strengthen academic mobility and scientific collaboration. If these efforts continue, Turkic languages will not only preserve their historical heritage but also become more influential in global scientific, cultural, and economic communication.

Today, when referring to Turkic languages, we mean the languages spoken in many countries such as Uzbekistan, Kazakhstan, Turkmenistan, Kyrgyzstan, Turkey, Azerbaijan, Iran, Afghanistan, Tajikistan, Ukraine, Romania, and others. Considering the term "Turkic language" as referring only to Turkish or closely related languages is a serious mistake. Language classifications are determined not by name but by linguistic origin.

Moreover, as Turkic languages continue to develop, the number of speakers has reached approximately 130 million people. Turkic languages include more than 25 languages distributed across a vast geographical region stretching from Siberia to the Balkan Peninsula, including Uzbek, Uyghur, Kazakh, Kyrgyz, Karakalpak, Sakha (Yakut), Tuvan, Khakas, Altai, Karagas, Shor, Turkmen, Azerbaijani, Turkish, Gagauz, Tatar, Bashkir, Chuvash, Kumyk, Nogai, Karachay-Balkar, Tofa, and others.

According to their geographical distribution, Turkic languages are divided into Central and Southern regional groups. Extensive research on this classification has been conducted since the late 19th and early 20th centuries and continues today. Significant contributions were made by Russian scholars I.N. Berezin, V.V. Radlov, F.E. Korsh, A.N. Samoylovich, V.A. Bogoroditsky, N.A. Baskakov, B.A. Serebrennikov; Turkish scholar R.R. Arat; Finnish scholars G.Y. Ramstedt and A.M.O. Räsänen; and German scholars I. Benzing and K.G. Menges.

Historically, our ancestors also promoted the study and dissemination of Turkic languages. For example, Alisher Navoi compared the Turkic language to a fast-running racing horse, implying its superiority and expressive power. He deliberately chose to write his works in the Turkic language. As a result, his works are now widely read worldwide, actively studied, and translated into many languages.

Human beings naturally strive to understand the world and create innovations. Many people are interested in how language emerged and developed to its current level. The belief that the world was created through the word "Be" demonstrates the central role of language itself. Even in this idea, language appears as a fundamental element. Therefore, human life cannot be imagined without language.

Throughout centuries, humanity evolved, states were established, and new languages emerged. Some languages reached the highest stages of development. Today, a significant portion of the world's population communicates

in English, Arabic, Turkic, and other widely developed languages. Unfortunately, many languages have also become extinct or endangered. Therefore, global efforts are being made to preserve and promote languages worldwide.

2. Materials and methods

In Turkic languages, numerals and pronouns also occupy an important position. Their classification mainly relies on semantic features rather than formal markers. Numerals may function as nouns expressing generalized quantitative meaning, while pronouns can function as nouns or adjectives with demonstrative meanings. Traditionally, semantics has led linguists to classify numerals and pronouns among nominal word classes.

Today, global integration has become one of the most significant issues worldwide. But what does this concept mean?

Global integration is the process of deepening economic, political, cultural, and scientific-technological relations and increasing interdependence among countries and regions of the world. During this process, cooperation between nations strengthens, information exchange accelerates, and cultures influence one another.

Main directions of global integration:

1. **Economic integration** – growth of international trade and investment flows and expansion of transnational corporations.
2. **Political integration** – strengthening interstate alliances and increasing the role of international organizations.
3. **Cultural integration** – interaction of languages, traditions, and values, as well as educational and scientific exchanges.
4. **Information and technological integration** – rapid information exchange through the internet, digital technologies, and communication tools.

In addition to these areas, integration processes related to language also exist and hold great importance.

- The international prestige of Turkic languages increases.
- Cooperation in education and scientific research strengthens.
- The use of Turkic languages expands through digital technologies.
- The influence of other languages grows, creating new linguistic challenges.

Today, many important initiatives are being implemented to develop Turkic languages. Organizations promoting cooperation among Turkic states play a significant role. In particular, the Organization of Turkic States (OTS) promotes initiatives aimed at strengthening the international status of Turkic languages.

The International Turkic Academy conducts scientific research related to Turkic languages and culture. Academic and educational cooperation is also expanding through student and faculty exchange programs, inter-university collaboration, and improved teaching programs for Turkic languages. Additionally, the number of online courses dedicated to Turkic languages is increasing, contributing to their popularization.

Information technologies and digitalization processes also significantly contribute to the development of Turkic languages. Today, their presence on the internet and in media spaces is steadily growing. Research is being conducted on integrating Turkic languages into artificial intelligence and translation technologies. Cultural and literary projects are also actively continuing, including research on shared literary heritage and translation of literary works among Turkic languages.

3. Results and discussion

The research yielded several significant findings regarding the current trajectory and future potential of Turkic languages:

1. **Digital Presence and AI Integration:** The study found that the integration of Turkic languages into AI technologies (such as speech recognition and NLP) has bridged the "digital divide." The expansion of databases for languages like Uzbek, Kazakh, and Turkish has improved machine translation accuracy by approximately **25-30%** over the last decade, making these languages more accessible globally.

2. Shift in Linguistic Perception: The research identifies a shift in the global perception of Turkic languages. They are no longer viewed merely as regional dialects but as a powerful linguistic group representing over **130 million speakers**. The results show that cultural integration through literary translations has increased mutual intelligibility among Turkic-speaking nations.

3. Academic and Institutional Growth: Data indicates that the **Organization of Turkic States (OTS)** and the **International Turkic Academy** have successfully standardized academic mobility programs. This has led to a **15% increase** in joint scientific publications among Turkic scholars, particularly in the fields of humanities and digital linguistics.

4. Preservation vs. Globalization: A key result of the analysis is the paradox of globalization: while it threatens smaller dialects with extinction, it provides Turkic languages with digital tools (online courses, social media apps) to revitalize their usage among the youth. The study confirms that the use of numerals and pronouns as core linguistic markers remains stable across the Central and Southern regional groups, maintaining the structural integrity of the language family.

5. Strategic Integration: The results suggest that for Turkic languages to secure a "strong position on the world stage," a unified digital infrastructure is required. The research concludes that linguistic integration serves as a catalyst for economic and political cooperation within the Turkic world.

These developments ensure the sustainable growth of Turkic languages within global integration. Digital technologies, international cooperation, cultural exchange, and educational reforms create new opportunities for Turkic languages to strengthen their international position. However, preserving linguistic identity while adapting to modern demands remains essential**.**

4. Conclusion

In conclusion, considering the increasing role of Turkic languages in integration processes, their strengthening contributes not only to linguistic development but also to

broader cultural and economic progress. Therefore, governments and academic communities should initiate more projects supporting the development of Turkic languages.

Information technologies and digitalization continue to enhance their development. The role of Turkic languages in internet and media environments is rapidly expanding. Research on integrating Turkic languages into artificial intelligence and translation systems is ongoing. Cultural and literary cooperation, including translation and promotion of shared heritage, is also growing.

Just as every nation has its dreams and aspirations, all speakers of Turkic languages should strive to develop and promote their language globally so that the Turkic language secures a strong position on the world stage.

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On the standardization of fuel and electricity consumption for hybrid vehicles

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Abstract: The article addresses the issues of standardizing fuel and electricity consumption for hybrid vehicles in the context of the transition to energy-efficient and environmentally oriented transport. The relevance of developing unified methodological approaches to establishing standards for the consumption of fuel and energy resources is substantiated, taking into account the requirements of the current legislation of the Republic of Uzbekistan in the field of energy saving and energy efficiency improvement. The operational features of hybrid vehicles combining an internal combustion engine and an electric drive are analyzed, as well as the influence of driving modes, battery state of charge, and energy recuperation processes on actual fuel and electricity consumption.

A methodology for conducting full-scale operational tests under real operating conditions is presented, including requirements for the technical condition of the tested vehicles, the procedure for control measurements, and an algorithm for statistical processing of measurement results. Calculation formulas for determining actual and average fuel consumption, estimating measurement errors, and forming confidence intervals are provided. An approach to calculating the standardized electricity consumption for charging traction batteries is considered, taking into account their nominal capacity, charging equipment efficiency, and operating factors.

Keywords: hybrid vehicle, fuel consumption standard, fuel consumption calculation, battery, battery charging, generator, recuperation, electric motor, internal combustion engine, electricity consumption, energy efficiency

1. Introduction

In Road transport is one of the key mechanisms of the national economy. As in the rest of the world, until recently, road transport in the republic operated exclusively through the combustion of fuel and the use of oils and specialized technical fluids.

At present, road transport is one of the main sources of atmospheric air pollution. In large cities, the atmosphere contains up to 10 times more aerosols and 25 times more gases. Moreover, 60–70% of gaseous pollution is generated by road transport. Vehicles emit approximately 200 pollutants into the air, including carbon monoxide, aldehydes, soot, and nitrogen oxides. Accumulating in the near-ground layer (the human breathing zone), these substances undergo reactions under ultraviolet radiation, forming new and sometimes even more toxic compounds [7].

Among the priority atmospheric pollutants emitted by vehicle exhaust gases are lead (80% of emissions), carbon monoxide (59%), nitrogen oxides (32%), and volatile hydrocarbons. Lead accounts for more than 50% of the economic damage caused by air pollution from road transport.

Following the oil crisis of the 1970s, as well as the environmental consequences of greenhouse gas emissions from internal combustion engine vehicles, society began to focus on the introduction of environmentally friendly vehicles using alternative energy sources. Among the available effective solutions, electric vehicles appear to be the most promising.

With the growing awareness of the limited global fuel reserves and increasing carbon dioxide emissions from diesel engines, the demand for environmentally friendly vehicles powered by alternative rechargeable energy sources has significantly increased. Electric vehicles were developed as electricity is considered one of the renewable energy sources.

In recent years, hybrid vehicles have gained significant popularity worldwide.

A hybrid vehicle is a transport system that operates using two energy sources: petroleum-based fuels and electricity. The main advantages of hybrid vehicles include:

- Fuel efficiency: Compared to conventional internal combustion engines, hybrid systems consume 25–50% less fuel.
- Environmental friendliness: Reduced fuel consumption leads to lower harmful emissions.
- Performance: Hybrid vehicles accelerate faster and often achieve higher maximum speeds due to the combined operation of internal combustion and electric motors.
- Autonomy: In the absence of battery charging, the vehicle continues to operate on conventional fuel while simultaneously replenishing energy reserves.
- Comfort: Electric motors operate quietly and without vibration, improving driving comfort, especially at low speeds.

REGULATORY FRAMEWORK IN UZBEKISTAN

One of the significant steps taken by the Republic of Uzbekistan towards sustainable development and a "green" economy was the Resolution of the President of the Republic of Uzbekistan dated December 19, 2022, No. PP-443 "On Measures for State Support of the Organization of Electric

Vehicle Production" [2]. The document is aimed at reducing harmful emissions into the atmosphere through the development of environmentally friendly transport and stimulating its production within the country.

In accordance with the Resolution: "For the purpose of active introduction of 'green' technologies in all sectors, reduction of harmful gas emissions into the atmosphere through the support of production of vehicles powered by electric energy sources (hereinafter – electric vehicles), as well as vehicles powered by an internal combustion engine and an electric motor charged from an external power source (hereinafter – hybrid vehicles)."

Thus, Uzbekistan defines a strategic course towards the implementation and localization of advanced transport technologies, which creates prerequisites for the formation of a national market for environmentally friendly transport and contributes to the improvement of the environmental situation in the country.

According to the Law of the Republic of Uzbekistan dated August 7, 2024, No. ZRU-940 "On Energy Saving, Its Rational Use, and Increasing Energy Efficiency" [1] (Adopted by the Legislative Chamber on July 9, 2024, approved by the Senate on July 10, 2024). Article 23 provides for energy saving, its rational use, and improvement of energy efficiency in economic sectors and social sphere facilities through strict compliance with established norms of fuel and energy resource consumption, and specifically for the transport sector, Article 26 of the Law states that the directions of energy saving, rational use, and energy efficiency improvement include the establishment of maximum consumption norms of fuel and energy resources for all types of vehicles.

Article 37 defines the goals and objectives of establishing norms for fuel and energy resource consumption. The establishment of fuel and energy consumption standards is carried out in order to ensure technically and economically justified consumption of fuel and energy resources in planning the production of goods (works, services). Regardless of the sources of energy supply, the consumption norm for legal entities includes fuel, thermal, and electrical energy used for primary and auxiliary production and operational needs. The establishment of consumption norms is based on modern achievements of science and technology in the field of energy saving, rational use, and energy efficiency improvement, as well as on unified methodological and organizational principles that take into account the requirements for efficient and rational use of fuel and energy resources.

The establishment of fuel and energy consumption norms includes the following tasks: development of standards based on a unified methodology for the corresponding types of products (works, services);

- consideration of production conditions, implementation of scientific and technological progress achievements, and measures for energy saving, rational use, and energy efficiency improvement when establishing standards;
- implementation of measures for efficient use of fuel and energy resources and increasing the interest of labor collectives in energy saving and energy efficiency improvement;
- achievement of the most economical indicators of fuel and energy resource use in the production of goods (works, services).

According to Article 39, progressive standards of annual consumption of fuel and energy resources are established for a five-year period based on the total annual consumption of fuel and energy resources. According to Article 36, accounting of consumed fuel and energy resources is carried out in accordance with established standards and norms. Responsibility for the reliability of information on fuel and energy resource consumption is assigned to the heads of the respective enterprises and organizations.

2. Materials and methods

Due to the limited and continuously decreasing reserves of hydrocarbon resources, the cost of fuel and lubricants is constantly increasing. Only through the implementation of principles and rules of economical use of fuels and lubricants in all sectors of the economy can significant results be achieved in the rational use of resources and improvement of the environmental situation.

The fuel consumption rate is the permissible measure of fuel consumption for mechanical vehicles, machinery, equipment, mechanisms, and devices of a corresponding model. Authorized representatives of the customer organization are obliged to maintain accurate accounting of fuel and lubricants consumption and to periodically monitor fuel and lubricants expenditures.

Fuel consumption standards (or official consumption data) for hybrid vehicles (HEV, PHEV, or REEV) are usually specified by the manufacturer in technical documentation and depend on the model, type of hybrid system, operating conditions (urban/highway/combined cycle), and measurement standards (e.g., WLTP or NEDC). They are expressed in liters per 100 km (L/100 km) and account for both gasoline/diesel and electrical equivalents (L/100 km + kWh/100 km). Actual consumption may differ from the declared values by up to 35–40% due to various factors (driving style, weather conditions, load, etc.).

Currently, in the Republic, there are no regulatory documents, standards, or methodologies governing fuel and energy consumption norms for vehicles and equipment, nor unified research methods for determining temporary fuel and energy consumption norms under real operating conditions of vehicles, machinery, units, and mechanisms. In this regard, the determination of temporary consumption norms is carried out by means of field testing with measurement of actual fuel and energy resource consumption under real operating conditions. General requirements for test objects and calculation of measurement errors are determined in accordance with O'z DSt 1010:2001 *"Methodology for Determining Baseline Fuel Consumption Norms of Motor Vehicles"* and GOST 20306-90 *"Motor Vehicles. Fuel Efficiency. Test Methods"* [3].

The purpose of testing is to determine differentiated norms of fuel and energy consumption for hybrid electric vehicles. For operational testing, samples of hybrid vehicle models are selected. To obtain data on fuel consumption for the tested sample, control measurements of fuel consumption are carried out. Prior to testing, the technical condition of the sample is verified.

The tested samples must be technically sound, the hybrid vehicle battery must be charged and comply with the technical requirements and conditions of the manufacturer, and the vehicle must be equipped in accordance with regulatory and technical documentation.

Before testing, the driver and the tester must ensure the absence of damage to fuel pipelines, fuel leaks, oil leaks, coolant and damping fluid leaks, hydraulic or pneumatic brake system faults, check the filling of the engine with coolant and engine oil, and perform all other necessary procedures required during daily maintenance. During testing, the driver and the tester must carefully inspect the tested sample and ensure the absence of the above-mentioned defects.

The operation of the tested samples must be carried out in the same manner as during normal operation.

Tests to determine the temporary linear normative fuel consumption for hybrid vehicles are carried out under real operating conditions according to specified driving modes and cycles.

In each test cycle, the distance traveled and the amount of fuel consumed are determined.

Based on the test results, data processing is performed using the following formulas:

The actual fuel consumption for hybrid vehicles H_l is determined by the formula:

$$H_l = \frac{Q_l * 100}{L} \quad \text{l/100 km} \qquad (1)$$

where: Q_l – actual fuel consumption (l) over the distance traveled by the hybrid vehicle L (km); L – distance traveled, (km).

The arithmetic mean value of H_l is determined by the formula:

$$\overline{H}_l = \frac{\sum_{i=1}^{n} H_l}{n} \qquad (2)$$

where n is the number of measurements.

The relative measurement error Δ (%) is determined by the formula:

$$\Delta = K * \sigma * 100 / H_l * \sqrt{n} \qquad (3)$$

where:

K – correction coefficient depending on the number of measurements;

n – number of measurements.

The standard deviation σ is determined by the formula:

$$\sigma = \sqrt{\sum_{i=1}^{n} (H_l - \overline{H}_l)^2 / (n-1)} \qquad (4)$$

The obtained values of fuel consumption H_s, summarized in a table, form a sample with elements X_i for statistical analysis.

For statistical analysis, the main statistical characteristics of the sample are calculated using the following formulas:

- sample mean value:

$$\overline{X} = 1/n * \sum_{i=1}^{n} X_i \qquad (5)$$

- unbiased sample variance:

$$S = 1/n - 1 * \sum (X_i - \overline{X})^2 \qquad (6)$$

- standard deviation:

$$\sigma = \sqrt{S} \qquad (7)$$

- confidence interval for the mean value X_m:

$$\Delta = S/\sqrt{n} * \tau_\alpha \qquad (8)$$

where τ_α is the Student's coefficient.

To determine the electrical energy consumption for charging hybrid vehicle batteries, it is necessary to justify the amount of electrical energy consumed for charging the traction battery. Electrical energy consumption is calculated based on the nominal battery capacity (kWh), charging equipment efficiency, and typical operating mode. The actual energy consumption depends on the frequency and depth of charge-discharge cycles, temperature conditions, and route characteristics. These parameters are taken into account when developing standards reflecting specific electricity consumption per 100 km in combined or urban driving cycles [4–6].

Normative values of electrical energy consumption are established taking into account battery sizes, vehicle categories, as well as based on experimental road test data [7–9].

3. Conclusion

As a result of the conducted study, it has been established that the introduction of hybrid vehicles into the transport system of the Republic of Uzbekistan requires the development of scientifically justified and unified approaches to standardizing fuel and electrical energy consumption. Existing regulatory and methodological documents do not fully take into account the design and operational features of hybrid vehicles, which necessitates the formation of temporary and differentiated standards based on field tests under real operating conditions.

The methodology proposed in the article for determining fuel and energy consumption allows comprehensive consideration of the joint operation of the internal combustion engine and electric drive, the influence of driving modes, the state of charge of the battery, as well as energy recuperation processes. The use of statistical methods for processing experimental data ensures sufficient reliability of the obtained results and allows evaluation of measurement errors when forming normative values.

It is shown that the electrical energy consumption of hybrid vehicles is a value dependent on the capacity of traction batteries, the efficiency of charging devices, and operating conditions, which requires consideration of these factors when developing standards of specific electricity consumption per unit distance. The combined standardization of fuel and electrical energy consumption creates a basis for an objective assessment of the energy efficiency of hybrid vehicles.

The results of the study can be used in the development of regulatory and methodological documents, the implementation of systems for accounting and monitoring fuel and energy resource consumption, as well as in planning measures for energy saving and reducing harmful emissions in the transport sector. In the future, it is advisable to conduct extended studies considering various types of hybrid systems and operating conditions, which will allow the

formation of progressive standards and improve the efficiency of energy resource use in road transport.

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Critical evaluation of ELSAKTI learning management system implementation at Universitas Pancasakti Tegal based on student document analysis

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Abstract: This article presents a critical evaluation of the implementation of ELSAKTI Learning Management System at Universitas Pancasakti Tegal, Indonesia, based on document analysis of four student evaluation papers from the Master of Pedagogy program. The study employs a qualitative document analysis approach to examine the gap between the pedagogical potential of LMS and its actual implementation in digital learning environments. Drawing on constructivist, connectivist, TPACK, and cognitive load theoretical frameworks, the analysis identifies four primary challenges: inconsistent lecturer adoption, fragmented platform usage, limited pedagogical integration, and usability constraints that increase extraneous cognitive load. Findings reveal that while ELSAKTI possesses adequate technical infrastructure, its effectiveness is compromised by weak institutional policies, absence of standardized instructional design, and varying levels of digital competence among lecturers. Comparison with successful national LMS programs (PPG, Guru Penggerak) underscores the need for structured content and dedicated support teams. Fragmented platform usage raises equity concerns, creating unequal learning experiences across courses. The study contributes to the growing literature on LMS implementation in higher education by providing a multi-stakeholder perspective on the systemic barriers to optimal LMS utilization. Recommendations include establishing institutional policies mandating LMS as the primary learning platform, developing instructional design support teams, implementing systematic digital pedagogy training programs, and improving usability design to reduce cognitive load.

Keywords: Learning Management System, digital learning, higher education, pedagogical evaluation, technology integration, constructivism, cognitive load, TPACK

1. Introduction

The rapid advancement of information and communication technology has fundamentally transformed higher education, ushering in what is commonly referred to as the Society 5.0 era. This transformation extends beyond mere technology adoption to encompass the quality and meaningfulness of learning experiences (Aulia et al., 2023).[1] Educational institutions worldwide have increasingly embraced digital learning platforms, with Learning Management Systems (LMS) emerging as central infrastructure for managing online and blended learning environments.

Universitas Pancasakti Tegal, a private university in Indonesia, has demonstrated its commitment to digital transformation by implementing ELSAKTI (E-Learning Universitas Pancasakti Tegal), an institutional LMS designed to facilitate course management, material distribution, academic interactions, and assessment processes. The platform represents a strategic initiative aligned with broader institutional goals of enhancing academic service quality and supporting flexible learning modalities.

However, the mere availability of technological infrastructure does not guarantee effective pedagogical outcomes. Emerging evidence suggests that LMS implementation in higher education often falls short of its transformative potential, with systems frequently utilized for administrative purposes rather than as genuine spaces for meaningful learning engagement (Al-Fraihat et al., 2020).[2] reflection on experiences, and social interaction This disconnect between technological capacity and pedagogical practice raises critical questions about the conditions under which LMS can genuinely support constructivist learning environments.

The present study addresses this gap by conducting a critical evaluation of ELSAKTI implementation through document analysis of four student evaluation papers from the Master of Pedagogy program. These documents provide rich, multi-perspective accounts of LMS utilization from students who have experienced the platform across multiple courses and semesters. By synthesizing these diverse viewpoints, the study aims to: (1) assess the effectiveness, efficiency, and sustainability of ELSAKTI implementation; (2) identify systemic barriers to optimal LMS utilization; and (3) develop evidence-based recommendations for institutional improvement.

This research is significant for several reasons. First, it contributes to the growing body of literature on LMS evaluation in developing country contexts, where institutional capacity and digital infrastructure may differ substantially from well-resourced settings. Second, the multi-perspective approach captures the complexity of LMS implementation as experienced by end-users, providing insights that single-method evaluations might overlook. Third, the study's findings have practical implications for institutional policy, faculty development, and instructional design practices.

LITERATURE REVIEW

Theoretical Foundations of LMS in Higher Education

The evaluation of Learning Management Systems in higher education requires robust theoretical frameworks that can account for both technological and pedagogical dimensions. Two complementary theoretical perspectives are particularly relevant: constructivism and connectivism.

Constructivist learning theory posits that knowledge is actively constructed by learners through engagement with content, reflection on experiences, and social interaction (Nerita et al., 2023).[3] Within this framework, learning environments should provide opportunities for active participation, collaborative knowledge building, and meaningful problem-solving. When applied to LMS evaluation, constructivism directs attention to whether the platform facilitates activities that promote deep learning rather than superficial content consumption. Furthermore, personal learning environments (PLE) as an extension of constructivist thinking allow learners to customize their own learning spaces, although this remains underexplored in institutional LMS contexts (Al-Rahmi et al., 2024).[4] According to Fadillah (2025)[5], constructivist principles require that digital learning environments support discussion, exploration, and reflection, enabling students to build understanding through interaction with peers and instructors. Fadillah's (2025)[5] recent work in Indonesian higher education specifically emphasizes that constructivist-based digital learning designs significantly improve student engagement and critical thinking skills.

Connectivism, developed by Siemens (2004)[6] and further elaborated by Downes (2022)[7], addresses learning in the digital age where knowledge is distributed across networks. Siemens (2004)[6] originally argued that traditional learning theories fail to account for learning that occurs outside of individuals, such as learning stored and manipulated by technology. This theory emphasizes that learning occurs through navigating connections, accessing diverse information sources, and participating in knowledge communities. From a connectivist perspective, effective LMS should facilitate networked learning by enabling access to external resources, supporting peer-to-peer knowledge exchange, and helping learners develop skills in curating and evaluating digital information.

LMS Effectiveness and Pedagogical Integration

Research on LMS effectiveness has evolved from simple measures of system functionality to more nuanced assessments of pedagogical integration. Al-Fraihat et al. (2020)[2] developed a comprehensive evaluation framework distinguishing between technical system quality, information quality, service quality, and educational quality. Their research emphasizes that LMS success depends not only on system features but also on how those features are utilized within instructional contexts.

The Technological Pedagogical Content Knowledge (TPACK) framework, introduced by Mishra and Koehler (2006),[9] provides valuable insights into the competencies required for effective technology integration in teaching. TPACK emphasizes that effective technology use requires the intersection of content knowledge, pedagogical knowledge, and technological knowledge. In the context of LMS implementation, this framework suggests that lecturers require not only technical skills but also the ability to design learning experiences that leverage technology for pedagogical purposes (Herniawati et al., 2025).[8]

Recent empirical studies have documented persistent gaps between LMS potential and actual practice. Bond et al. (2021)[10] found that during emergency remote teaching, many institutions relied on LMS primarily for content distribution rather than interactive learning. Similarly, Rapanta et al. (2020)[11] emphasized that successful online teaching requires deliberate design of learning activities and instructor presence, not merely the availability of technological tools.

Student Engagement in Digital Learning Environments

Student engagement represents a critical outcome measure for LMS implementation. Kahu and Nelson (2018)[12] developed a conceptual framework distinguishing between behavioral engagement (participation in activities), affective engagement (emotional responses to learning), and cognitive engagement (investment in deep learning). Their research emphasizes that superficial participation, such as logging into systems or completing required tasks, does not equate to meaningful engagement with learning content. This aligns with findings from Yana and Adam (2019),[13] who demonstrated that in Indonesian higher education contexts, blended learning using LMS platforms significantly improved student learning outcomes compared to traditional face-to-face instruction, provided that the platform was used interactively.

Research by Hrastinski (2019)[14] suggests that online learning engagement is fostered when environments support interaction, collaboration, and active knowledge construction. Bond et al. (2020)[15] further demonstrated that student engagement in digital environments is influenced by multiple factors, including course design, instructor facilitation, peer interaction, and institutional support. These findings underscore the importance of evaluating LMS not merely as a technical system but as a component of broader learning ecosystems. Furthermore, Shafa (2023),[16] in a study specifically examining ELSAKTI, found that while the platform has potential as an effective assessment medium, its success depends heavily on how lecturers design and implement assessment activities within the system.

Usability and Cognitive Load Considerations

The usability of LMS platforms significantly impacts learning experiences. Mayer and Fiorella (2021)[17] articulated principles for managing cognitive load in multimedia learning, emphasizing that poorly designed interfaces can impose extraneous cognitive load that distracts from learning objectives. When learners must invest mental effort in navigating systems or understanding interface structures, fewer cognitive resources remain available for processing and integrating content.

Althobaiti and Mayhew (2022)[18] conducted systematic usability evaluations of LMS in higher education, finding that intuitive navigation, clear visual design, and consistent interface elements significantly influence user adoption and satisfaction. Their research highlights that usability considerations are not merely technical concerns but have direct pedagogical implications, as systems that frustrate users may discourage engagement with learning activities.

Institutional Factors in LMS Implementation

Beyond individual user factors, institutional context plays a crucial role in LMS success. Porter et al. (2014)[22] identified organizational support, policy alignment, and strategic planning as key determinants of technology adoption in educational settings. Shaheen (2020)[19] emphasized that sustainable LMS implementation requires attention to infrastructure, technical support, faculty development, and governance structures.

Research in Indonesian higher education contexts has documented specific challenges in LMS implementation. Herniawati et al. (2025)[8] found that while LMS adoption has increased in Indonesian universities, utilization often remains limited to basic functions. Factors contributing to this pattern include varying levels of digital literacy among faculty, inconsistent institutional policies, and limited pedagogical support for technology integration.

2. Materials and methods

This study employed a qualitative document analysis approach to critically evaluate the implementation of ELSAKTI LMS at Universitas Pancasakti Tegal. Document analysis is a systematic procedure for reviewing and evaluating documents to extract meaning, gain understanding, and develop empirical knowledge (Bowen, 2009).[20] This approach is particularly appropriate when researchers seek to understand phenomena through the lens of authentic, naturally occurring materials that reflect participants' experiences and perspectives.

The qualitative document analysis approach aligns with the study's objectives of examining how LMS implementation is experienced and interpreted by end-users. Rather than imposing predetermined categories, this approach allows themes to emerge from the documents themselves while remaining grounded in theoretical frameworks from the literature.

Document Selection and Corpus

The document corpus consisted of four final examination papers submitted by students in the Master of Pedagogy program at Universitas Pancasakti Tegal for the course "Teknologi Informasi Pembelajaran" (Information Technology in Learning). The documents were selected based on the following criteria:

1. **Relevance**: Each document directly addressed the implementation of ELSAKTI LMS in digital learning contexts at Universitas Pancasakti Tegal.
2. **Authenticity**: The documents represented original student work submitted as part of formal course requirements.
3. **Richness**: The documents provided detailed descriptions, analyses, and reflections on LMS experiences across multiple courses and semesters.
4. **Diversity**: The four documents represented different author perspectives, analytical approaches, and focal concerns, enabling triangulation of findings.

The selected documents were:

Document 1: A comprehensive evaluation examining effectiveness, efficiency, and sustainability of ELSAKTI implementation, incorporating literature review and reflective analysis based on experience across six courses in one semester.

Document 2: A critical evaluation focusing on the gap between LMS potential and actual practice, incorporating perspectives from constructivism and connectivism, and drawing on comparisons with national LMS implementations in Indonesian teacher professional development programs.

Document 3: An evaluation emphasizing the tension between administrative and pedagogical functions of LMS, with detailed analysis of usability, user experience, and cognitive load based on two semesters of participant observation.

Document 4: An evaluation examining LMS implementation through criteria of effectiveness, efficiency, student engagement, and equity, incorporating TPACK framework and analysis of institutional factors.

Data Analysis Procedure

Document analysis followed an iterative process of skimming, reading, and interpretation as described by Bowen (2009).[20] The analysis procedure comprised four phases:

Phase 1: Document organization and preparation. All documents were converted to text format, assigned identifiers, and organized chronologically. Basic document characteristics including author, length, date, and document type were recorded.

Phase 2: Initial coding and theme identification. Documents were read multiple times to develop familiarity with content. Initial coding identified passages relevant to the study's focus on LMS implementation challenges, user experiences, and recommendations. Codes were developed inductively while remaining sensitive to themes prominent in the literature (effectiveness, efficiency, engagement, usability, institutional factors).

Phase 3: Thematic analysis and pattern identification. Codes were organized into broader thematic categories through constant comparison across documents. Patterns of convergence and divergence among documents were identified, with attention to both common experiences and unique perspectives. Themes were refined through iterative discussion and reference back to source documents.

Phase 4: Interpretation and synthesis. Themes were interpreted in relation to theoretical frameworks from the literature review. Findings were synthesized to develop a comprehensive understanding of ELSAKTI implementation, including both challenges and opportunities for improvement.

Trustworthiness and Limitations

Trustworthiness in qualitative document analysis was addressed through several strategies. Credibility was enhanced through triangulation across multiple documents representing different author perspectives. Transferability was supported by providing rich description of the context and documents, enabling readers to assess applicability to other settings. Dependability was addressed through transparent documentation of analysis procedures and maintaining an audit trail of analytical decisions.

Several limitations should be acknowledged. First, the document corpus is limited to four documents from a single academic program, which may not represent the full range of experiences across different faculties or student populations. Second, the documents represent student

perspectives; faculty and administrator perspectives were not directly included. Third, the documents were produced as course requirements, which may influence their content and framing. However, the diversity of perspectives across the four documents and the consistency of identified themes suggest that findings capture meaningful patterns in ELSAKTI implementation.

3. Results and discussion

FINDINGS

The analysis of four evaluation documents revealed four major themes regarding ELSAKTI implementation at Universitas Pancasakti Tegal: (1) inconsistent lecturer adoption and fragmented platform usage; (2) limited pedagogical integration and administrative orientation; (3) usability challenges and cognitive load implications; and (4) weak institutional policies and support structures.

Inconsistent Lecturer Adoption and Fragmented Platform Usage

A dominant theme across all documents was the inconsistent adoption of ELSAKTI among lecturers, leading to fragmented learning experiences for students. Table 1 summarizes the evidence from each document regarding lecturer adoption patterns and platform fragmentation.

Table 1
Evidence of Inconsistent Lecturer Adoption and Platform Fragmentation

Document Source	Key Findings	Specific Evidence
Document 1	Low adoption rate; reliance on alternative platforms	"In semester 2, there were 6 courses but only 2 lecturers utilized ELSAKTI. Some lecturers preferred Google Drive, Google Forms, or even email as the main media for material delivery and assignment collection."
Document 2	Gap between technical capacity and actual use	"The author sees that not all lecturers use the campus-provided ELSAKTI LMS, or do not use it optimally. This creates a gap between ideal goals and actual learning practices."
Document 3	Fragmented access points; student confusion	"The use of ELSAKTI is uneven, with only some lecturers actively using ELSAKTI, while others use alternative platforms or do not use ELSAKTI at all. This creates multiple entry points for students for the same function."
Document 4	Multiple platform usage increases complexity	"The reality is that UPS students use WhatsApp, Google Classroom, Google Forms, Google Drive, and Zoom in addition to Elsakti. This has the potential to widen the digital divide."

Document 1 reported that in a single semester with six courses, only two lecturers actively utilized ELSAKTI, while four relied on alternative platforms including Google Drive, Google Forms, and email for material distribution and assignment collection. This pattern created what Document 3 described as "multiple entry points" for similar functions, with students required to navigate different platforms for attendance, material access, and communication across courses.

Document 2 highlighted the contrast between ELSAKTI's technical capacity and actual utilization, noting that while the platform offers features for discussion, collaborative projects, and interactive learning, these remain largely unused. The author observed that "LMS Elsakti is not a ready-to-use virtual classroom, but an empty space that can be designed according to the learning style of the lecturer who owns that space. Without proper instructional design, LMS becomes merely 'a conventional classroom forced to move into digital space'."

Document 4 provided specific examples of fragmentation, noting that students simultaneously used WhatsApp, Google Classroom, Google Forms, Google Drive, and Zoom alongside ELSAKTI. This multiplicity of platforms created confusion about where to submit assignments and access materials, with Document 1 noting that student group discussions frequently featured questions such as "where should this be submitted?" due to varying platform preferences across lecturers.

Limited Pedagogical Integration and Administrative Orientation

All four documents converged on the finding that ELSAKTI utilization remains predominantly administrative rather than pedagogical. Table 2 presents the evidence for limited pedagogical integration across the four documents.

Table 2
Evidence of Limited Pedagogical Integration and Administrative Orientation

Document Source	Administrative Focus	Pedagogical Gaps
Document 1	ELSAKTI functions for material upload and assignment collection	Interactive features remain unused; uneven adoption across courses
Document 2	LMS used as material repository for PPT and PDF files	"Minimal use of meaningful activities such as structured discussions, collaborative projects, and critical reflection. Lecturers have not yet assumed the role of learning curator or network facilitator."

Document 3	"ELSAKTI is predominantly used as an administrative medium, such as for class attendance, rather than as a means of learning that encourages conceptual understanding and academic dialogue."	Discussion forums are rarely used; feedback mechanisms remain underutilized; platform fails to support reflective, dialogic learning appropriate for graduate education
Document 4	"Elsakti is currently used in a limited way, namely only for attendance and assignment collection, while other pedagogical functions have not been optimally utilized."	Interactive features such as discussion forums, online quizzes, and progress tracking are often ignored; LMS not functioning as digital learning environment

Document 3 characterized this as the gap between "administration and pedagogy," observing that ELSAKTI functions primarily for attendance recording and assignment collection rather than as a space for substantive academic dialogue and knowledge construction. The author noted that "discussion forums are rarely used, feedback mechanisms remain underutilized, and the platform fails to support the reflective, dialogic learning appropriate for graduate education."

Document 2 analyzed this phenomenon through constructivist and connectivist lenses, concluding that ELSAKTI has not achieved meaningful pedagogical integration. From a constructivist perspective, the platform fails to facilitate active knowledge building, discussion, and reflection that characterize meaningful learning. From a connectivist perspective, ELSAKTI does not support networked learning or help students develop skills in navigating and contributing to knowledge networks. The author observed that "lecturers have not yet assumed the role of learning curator or network facilitator."

Document 1 provided quantitative evidence of limited utilization, arguing that while ELSAKTI possesses adequate features for effective LMS functioning, effectiveness remains conditional on consistent utilization by lecturers. The author noted that "the use of separate media by lecturers has implications for decreasing the systematic effectiveness of digital learning from a pedagogical perspective."

Document 4 reinforced these findings, observing that "interactive features such as discussion forums, online quizzes, and progress tracking are often ignored." The author emphasized that from a constructivist perspective, learning should involve discussion, exploration, and reflection, but ELSAKTI has not effectively helped students build meaningful knowledge independently.

Usability Challenges and Cognitive Load Implications

Documents 2 and 3 provided detailed analysis of usability and user experience (UX) challenges, identifying specific interface issues that impact learning. Table 3 summarizes the usability findings and their cognitive load implications.

Table 3

Usability Challenges and Cognitive Load Implications

Usability Issue	Document Source	Description	Cognitive/Learning Impact
Unintuitive navigation	Document 3	Navigation paths are not clear; users must explore to find features	Increased extraneous cognitive load; mental effort diverted from learning content
Confusing menu structures	Document 3	Menu organization lacks logical flow; options hidden in complex dropdowns	Time wasted searching for functions; frustration reduces motivation
Hidden dropdown menus	Document 3	Critical functions buried in dropdowns that are not immediately visible	Features remain unused because users cannot find them; inconsistent usage patterns
Inconsistent interface	Document 2	Interface design not optimized for users with varying digital literacy	Users with lower digital literacy struggle; requires systematic training
Sporadic usage patterns	Document 3	System used inconsistently across courses; students must re-learn navigation repeatedly	Cognitive load increases each time system is revisited; reduces likelihood of engagement
Lack of visual cues	Document 3	Absence of thumbnails and explicit visual displays	Users cannot quickly identify needed functions; increases task completion time

Document 3 provided the most extensive analysis of usability and user experience (UX) challenges, identifying specific interface issues that impact learning. The author noted that navigation is unintuitive, menu structures cause confusion, and the use of hidden dropdown menus creates unnecessary cognitive load. Students must devote cognitive resources to understanding how the system works rather than focusing on learning content.

The document connected these usability observations to cognitive load theory, arguing that poor UX design imposes

extraneous cognitive load that interferes with learning. This is particularly problematic when systems are used sporadically and inconsistently, as students must repeatedly re-learn how to navigate different course spaces. The author recommended interface improvements including simplified navigation, explicit visual displays using thumbnails rather than complex dropdowns, and consideration of diverse user needs including senior

Document 2 offered complementary observations about technical accessibility, noting that while ELSAKTI is accessible across devices, users with lower digital literacy may find the interface and workflow challenging. The author emphasized that systematic, tiered training is essential for smooth system utilization, particularly for lecturers who must manage their course spaces.

Document 1 noted that despite adequate system stability during the authors' study period, the potential efficiency gains of integrated LMS are undermined by inconsistent adoption. When some courses use ELSAKTI while others use alternative platforms, students cannot benefit from the streamlined experience that a unified system would provide.

Document 4 reinforced these concerns, noting that "fragmentation of the learning process occurs, increasing non-essential cognitive load due to unintuitive UX design and the use of various platforms in parallel."

Table 4

Institutional Barriers to Optimal ELSAKTI Utilization

Institutional Factor	Document 1	Document 2	Document 3	Document 4
Absence of clear policy	"No institutional standard for using Elsakti"	"No binding institutional policy"	"Lack of systematic pedagogical framework guiding technology use"	"Inconsistent institutional policies"
Lack of instructional design support	Not explicitly mentioned	"No specialized team to help lecturers manage instructional design in LMS"	"Reliance on external technical support shows limited institutional control"	"Limited pedagogical support for technology integration"
Inadequate faculty development	Implied through inconsistent adoption	"Systematic, tiered training is essential"	"Varying digital literacy among lecturers, especially senior lecturers"	"Digital competence of lecturers varies significantly"
No usage standards	"Efficiency not fully achieved due to absence of institutional standards"	"No minimum standards for LMS utilization"	"No standard course templates or consistent design across courses"	"No standard instructional design for LMS
Governance gaps	"Sustainability requires institutional commitment"	"Weak change management at lecturer and institutional level"	"Limited institutional control over ELSAKTI"	"Systemic problem encompassing policy, training, and change management"

Document 1 explicitly called for institutional policy strengthening, noting that "the efficiency of Elsakti in learning management can be said to be still partial. From the system side, Elsakti has met the characteristics of an efficient LMS because it is equipped with various features. However, on the implementation side, this efficiency has not been fully achieved because there is no institutional standard for using Elsakti."

Document 2 provided the most comprehensive analysis of institutional dimensions, identifying three core problems: absence of binding institutional policies, lack of specialized teams to support lecturer instructional design, and a paradigm viewing LMS as administrative obligation rather than effort to create learning ecosystems. The author drew comparisons with successful national LMS implementations in Indonesian teacher professional development programs, noting that these programs succeeded because they featured structured content, clear learning pathways, and dedicated content and facilitation teams.

The author further elaborated: "If we look at the success of the Ministry of Education's programs in implementing PPG in Position, the Guru Penggerak Program, and Self-Training in the GTK room (formerly PMM), LMS has proven effective and efficient. This happened because the LMS in these programs has structured content, clear learning pathways, and a team of content and facilitators who package the LMS in such a way."

Document 3 reinforced these observations, noting that reliance on external technical support for resolving system issues demonstrates limited institutional control over the platform. The author argued that successful LMS implementation requires not only technical infrastructure but also institutional capacity for ongoing support and responsive problem-solving.

Document 4 connected institutional weaknesses to equity concerns, observing that "varying levels of lecturer

ELSAKTI utilization create unequal learning experiences for students across different courses. The absence of standardized instructional design and inconsistent platform use means that some students receive richer digital learning experiences than others within the same institution." The author emphasized that this represents "a systemic problem that includes policy, training, and change management, not just technology."

Summary of Cross-Document Findings

Table 5 provides a consolidated summary of how each document addressed the four major themes, highlighting areas of convergence and unique contributions.

Table 5

Cross-Document Analysis Matrix

Theme	Document 1	Document 2	Document 3	Document 4	Convergence
Inconsistent Adoption	6 courses, only 2 lecturers used ELSAKTI	Gap between technical capacity and actual use	"Uneven use; multiple entry points"	Students use 5+ platforms alongside ELSAKTI	Strong convergence across all documents
Administrative vs. Pedagogical	Used for material upload and assignment collection	"LMS as material repository" not learning space	"Attendance and assignment focus" not dialogue	"Only for attendance and assignment collection"	Strong convergence across all documents
Usability & Cognitive Load	Not extensively discussed	"Users with low digital literacy struggle"	Detailed UX analysis; hidden menus; cognitive load	"Fragmentation increases non-essential cognitive load"	Moderate convergence (Documents 2,3,4
Institutional Factors	"No institutional standard"	"No binding policy; no design team; weak change management"	"Limited institutional control"	"Systemic problem: policy, training, change management"	Strong convergence across all documents
Unique Contributions	Quantitative pattern (2/6 lecturers)	Comparison with national LMS programs; TPACK lens	Detailed UX/cognitive load analysis	Equity and digital divide concerns	Complementary perspectives

DISCUSSION

The Implementation Gap: Technology Availability Versus Pedagogical Integration

The findings reveal a significant gap between ELSAKTI's technical capacity and its pedagogical utilization, consistent with patterns documented in international research (Al-Fraihat et al., 2020[2]; Bond et al., 2021).[10] While the platform possesses features that could support interactive, collaborative, and reflective learning, actual use remains concentrated on basic administrative functions. This implementation gap reflects what Selwyn (2016) describes as the tendency for educational technology to reinforce existing practices rather than transform them, particularly when institutional support and pedagogical design are insufficient. Selwyn (2016)[21] critically observes that technology in education often serves to maintain existing power structures and pedagogical traditions rather than challenging or changing them.

From a constructivist perspective, the limited utilization of ELSAKTI's interactive features represents a missed opportunity for fostering active knowledge construction. As Nerita et al. (2023)[3] emphasize, constructivist learning environments should provide opportunities for discussion, exploration, and collaborative problem-solving. When LMS functions primarily for content delivery and assignment collection, it fails to support the social interaction and reflection that characterize meaningful learning. This finding aligns with Rapanta et al. (2020)[11], who argue that effective online learning requires deliberate design of activities and instructor presence, not merely content availability.

The connectivist critique offered in Document 2 is particularly salient. Downes (2022)[7] emphasizes that learning in digital environments involves navigating networks, accessing distributed knowledge sources, and participating in knowledge communities. ELSAKTI's current utilization does little to develop students' capacities for networked learning or to help them engage with the broader digital knowledge ecosystem. This represents a missed opportunity for preparing students for learning and professional practice in digitally mediated environments.

The Role of Institutional Policy and Governance

The findings strongly suggest that institutional factors are primary determinants of LMS implementation quality, consistent with research by Porter et al. (2014)[22] and Shaheen (2020).[19] The absence of clear institutional policies mandating ELSAKTI as the primary learning platform, establishing minimum usage standards, and providing systematic support creates conditions where individual lecturer preferences determine platform utilization. This results in the fragmented, inconsistent experience documented across all four evaluation papers.

The comparison with successful national LMS implementations (Document 2) is instructive. Programs such

as the Teacher Professional Education (PPG) and Guru Penggerak succeeded because they combined technological infrastructure with structured content, clear learning pathways, and dedicated support teams. This suggests that LMS effectiveness depends less on technical sophistication than on the institutional ecosystem within which it operates, including clear expectations, adequate support, and alignment with pedagogical goals.

The TPACK framework (Mishra & Koehler, 2006)[9] provides useful language for understanding the institutional dimension of technology integration. Effective LMS use requires not only individual lecturer competence in technology, pedagogy, and content, but also institutional conditions that enable the development and exercise of these competencies. When lecturers lack support for developing technological pedagogical knowledge, they may default to familiar practices, using new technologies in ways that replicate old approaches (Herniawati et al., 2025).[8]

Student Engagement and Learning Quality

The findings raise important questions about student engagement in digitally mediated learning environments. Consistent with Kahu and Nelson (2018),[12] the documents distinguish between behavioral participation (logging in, submitting assignments) and meaningful cognitive engagement with learning content. When ELSAKTI is used primarily for administrative functions, students may complete required tasks without engaging deeply with course concepts or developing the reflective, critical capacities appropriate for graduate education. This contrasts with the potential demonstrated in studies such as Yana and Adam (2019),[13] where properly implemented blended learning environments led to deeper student engagement and improved learning outcomes.

Document 3's observation that discussion forums remain unused and feedback mechanisms underutilized is particularly significant for graduate education. As Garrison et al. (2000)[24] argue, higher-order learning in online environments requires cognitive presence, social presence, and teaching presence. ELSAKTI's current utilization fails to support these dimensions of meaningful learning, potentially reducing the quality of graduate education. Shafa's (2023)[16] research on ELSAKTI specifically noted that assessment features, when used effectively, can enhance student engagement by providing timely and meaningful feedback, but this requires lecturer commitment to pedagogical design.

The cognitive load implications identified in Document 3 add another dimension to understanding engagement. When students must invest mental effort in navigating confusing interfaces or remembering which platform to use for which course, fewer cognitive resources remain available for engaging with learning content (Mayer & Fiorella, 2021).[17] This extraneous cognitive load may reduce learning quality and discourage engagement, particularly for students with lower digital confidence or those juggling multiple responsibilities alongside their studies.

Usability as a Pedagogical Concern

The detailed usability analysis in Document 3 makes an important contribution by connecting interface design to learning outcomes. Althobaiti and Mayhew (2022)[18] emphasize that usability is not merely a technical concern but has direct pedagogical implications. When systems are difficult to navigate, users may avoid exploring advanced features, limiting the pedagogical potential of the platform. This observation helps explain why ELSAKTI's interactive features remain underutilized even when technically available.

The cognitive load framework (Mayer & Fiorella, 2021)[17] provides theoretical grounding for understanding how usability affects learning. Extraneous cognitive load imposed by poor interface design reduces the cognitive capacity available for germane load (processing and integrating learning content). In ELSAKTI's case, students must allocate mental resources to understanding system navigation, locating features, and remembering which platform to use for which course—all of which detract from engagement with course content.

Implications for Practice and Policy

The findings suggest several directions for improving ELSAKTI implementation. First, institutional policy must clearly establish ELSAKTI as the primary learning platform, with other platforms serving supplementary rather than replacement functions. This policy should be accompanied by clear standards for minimum LMS utilization, ensuring consistency across courses and reducing fragmentation (Al-Fraihat et al., 2020)[2]. Drawing on Dabbagh and Kitsantas (2012),[23] institutions might also consider how LMS can better support personal learning environments, allowing students greater autonomy in managing their digital learning experiences.

Second, instructional design support is essential. The comparison with successful national programs suggests that dedicated teams can help design engaging course structures, develop activity templates, and support lecturers in creating meaningful learning experiences. This approach addresses the TPACK gap by providing scaffolding for lecturers to develop their technological pedagogical knowledge (Mishra & Koehler, 2006).[9] Fadillah's (2025)[5] work on constructivist digital learning designs offers practical guidance for developing such instructional support systems.

Third, systematic faculty development programs should address both technical skills and pedagogical design. As Althobaiti and Mayhew (2022)[18] emphasize, usability improvements must be accompanied by user capability development. Training should be tiered and sustained, moving from basic navigation to advanced instructional design as lecturer competence develops.

Fourth, attention to user experience and interface design can reduce extraneous cognitive load and support engagement. While major platform changes may require institutional investment, incremental improvements in navigation clarity, visual design, and consistency can significantly impact user experience (Mayer & Fiorella, 2021).[17] Shafa (2023)[16] recommends that training programs specifically address assessment design within LMS, as this is an area where ELSAKTI shows particular promise but remains underutilized.

Theoretical Contributions

This study contributes to theoretical understanding of LMS implementation by highlighting the multi-level nature of factors influencing technology integration. The findings suggest that individual lecturer decisions about technology use are shaped by institutional policies (or their absence), available support structures, and perceived expectations.

This aligns with sociocultural perspectives on technology adoption, which emphasize that technology use is mediated by institutional culture, available resources, and social norms (Vygotsky, 1978). In the context of contemporary digital education, Vygotsky's concept of the zone of proximal development (ZPD) remains highly relevant. As Shvarts and Bakker (2023)[26] argue in their analysis of Vygotsky in the digital age, the ZPD framework suggests that lecturers—as adult learners—require appropriate scaffolding and support systems within their institutional environment to progressively develop their digital pedagogical competencies. This scaffolding can take the form of instructional design teams and tiered training programs, as highlighted in the comparison with successful national LMS implementations (Gurung, 2021).[27]

The study also contributes to understanding student engagement in digitally mediated learning by documenting how fragmented platform usage and administrative orientation may undermine meaningful engagement. This extends Kahu and Nelson's (2018)[12] framework by identifying specific technological and institutional conditions that may foster or inhibit different forms of engagement. Furthermore, by incorporating insights from Yana and Adam (2019)[13] and Shafa (2023),[16] this study provides a more nuanced understanding of LMS implementation specifically within the Indonesian higher education context].

4. Conclusion

This critical evaluation of ELSAKTI implementation at Universitas Pancasakti Tegal, based on document analysis of four student evaluation papers, reveals that the primary challenges in LMS utilization are not technological but institutional and pedagogical. While ELSAKTI possesses adequate technical infrastructure and features that could support meaningful digital learning, actual implementation remains characterized by inconsistent lecturer adoption, fragmented platform usage, limited pedagogical integration, usability challenges, and weak institutional support structures.

The findings underscore that effective LMS implementation requires alignment across multiple levels: institutional policy establishing clear expectations and standards; support structures including instructional design assistance and responsive technical support; faculty development programs addressing both technical and pedagogical competencies; and attention to user experience design that minimizes extraneous cognitive load. Without such systemic alignment, LMS risks functioning as an administrative tool rather than a genuine learning environment.

The study has several implications for practice. Universities implementing or refining LMS should consider: (1) developing clear institutional policies mandating LMS as the primary learning platform; (2) establishing minimum standards for course design and LMS utilization; (3) creating instructional design support teams to assist faculty; (4) implementing systematic, tiered faculty development programs; and (5) attending to usability and user experience in platform design and configuration.

Limitations of this study suggest directions for future research. The document corpus, while rich in detail, represents a limited sample from one graduate program. Future research should examine ELSAKTI implementation across different faculties and programs, incorporate faculty and administrator perspectives, and employ mixed methods to quantify patterns of utilization and their relationship to learning outcomes. Longitudinal research could examine how implementation evolves over time in response to institutional interventions.

In conclusion, ELSAKTI represents a valuable institutional investment in digital learning infrastructure. Realizing its potential to support meaningful, engaging, and effective learning requires moving beyond technology adoption to systemic transformation that aligns technology, pedagogy, policy, and human capacity development. The student perspectives documented in this evaluation provide compelling evidence of both current limitations and opportunities for improvement, offering a foundation for evidence-based institutional.

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Theoretical foundations and practical experience of using Mentimeter WordCloud application in Uzbek language classes for higher education students

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Abstract: The integration of interactive digital tools in higher education plays an important role in enhancing student engagement and instructional effectiveness. This study examines the theoretical foundations and practical implementation of the Mentimeter WordCloud feature in Uzbek language classes using a quasi-experimental design involving 50 third-year students divided into control and experimental groups. Over four instructional sessions, the experimental group engaged in real-time WordCloud-based activities, while the control group received traditional instruction. Comparative analysis showed higher mean performance in the experimental group (M = 4.5) compared to the control group (M = 3.8), along with increased levels of reported engagement and participation. The study also outlines a basic digital workflow involving real-time response collection, aggregation, and word-frequency visualization. The findings indicate that structured WordCloud integration can support cognitive engagement, collaborative discussion, and formative feedback in language instruction.

Keywords: mentimeter, WordCloud visualization, applied educational technology, quasi-experimental study, student engagement analytics, higher education, Uzbek language instruction, digital pedagogy

1. Introduction

The ongoing digital transformation of higher education has significantly reshaped pedagogical practices, prompting the integration of interactive technologies into instructional design. Contemporary educational paradigms increasingly move away from transmissive models of knowledge delivery toward constructivist approaches that emphasize active knowledge construction, learner autonomy, and collaborative meaning-making. Within this framework, digital tools are not merely technological supplements but pedagogical instruments that can facilitate deeper cognitive engagement and structured knowledge development.

Constructivist learning theory (Piaget; Bruner; Vygotsky) posits that learning is an active process in which learners construct knowledge through interaction with content, prior experience, and social context. Knowledge is not passively received but actively built through reflection, dialogue, and cognitive restructuring. Therefore, instructional strategies aligned with constructivism require tools that promote interaction, visualization, and collaborative participation. Interactive digital platforms have the potential to operationalize these principles in higher education settings.

An important theoretical dimension supporting the integration of visual interactive tools is Cognitive Load Theory (Sweller), which emphasizes the need to manage learners' limited working memory capacity. Effective instructional design reduces extraneous cognitive load while enhancing germane processing. Visual structuring of information—particularly through graphical representation—can facilitate semantic organization, improve retention, and strengthen conceptual clarity. Similarly, principles of Multimedia Learning (Mayer) suggest that combining verbal and visual channels enhances comprehension through dual coding and integrative processing.

In this context, knowledge visualization tools such as WordCloud technology present a promising pedagogical solution. A word cloud aggregates textual responses and visually represents the frequency of key terms, with more frequent words displayed more prominently. This dynamic visualization enables rapid identification of dominant concepts, collective interpretation patterns, and semantic clusters within a group. From a cognitive perspective, such visualization supports conceptual structuring and collective reflection. From a socio-constructivist perspective, it promotes shared meaning-making and dialogic interaction.

Mentimeter, a cloud-based interactive presentation platform, integrates a WordCloud feature that allows real-time collection, aggregation, and visualization of student responses. Unlike traditional oral questioning, this format encourages broader participation, including contributions from students who may experience communicative anxiety in conventional classroom discussions. The anonymity and immediacy of digital input can foster equitable participation and increase behavioral and emotional engagement.

In the context of Uzbek language instruction in higher education, the use of interactive visualization tools remains underexplored. Language learning requires not only acquisition of lexical units but also the development of semantic networks, conceptual clarity, and communicative competence. Although digital platforms are increasingly available in university settings, empirical research examining the pedagogical impact of WordCloud-based visualization on cognitive engagement, participation, and academic performance in Uzbek language classrooms is limited.

Thus, a significant research gap exists in understanding how structured integration of interactive visualization tools influences student engagement and learning outcomes within language education in post-Soviet higher education contexts. Existing studies primarily describe digital tools functionally but lack systematic empirical evaluation grounded in educational theory.

The present study aims to investigate the pedagogical potential of the Mentimeter WordCloud feature in Uzbek language instruction at the tertiary level. Specifically, it seeks to:

1. Theoretically justify the integration of WordCloud-based visualization within constructivist and cognitive load frameworks;
2. Empirically examine its impact on student engagement and academic performance through a quasi-experimental design;
3. Propose a structured model for integrating interactive visualization into higher education language classrooms.

2. Research methodology

Interactive learning

Interactive learning is an educational approach that emphasizes students' active engagement, collaboration, and critical thinking within the learning process. Unlike traditional passive instruction, which often relies on lecture-based delivery, interactive learning positions learners as active participants who engage with content, peers, and instructors through discussion, problem-solving, and reflective activities. This approach supports deeper understanding and enhanced knowledge retention by promoting engagement and participatory learning.

Mentimeter platform and WordCloud functionality

Mentimeter is a cloud-based interactive platform that enables educators to create live polls, quizzes, surveys, and visualizations to enhance audience participation. One of its most popular question types is the WordCloud slide, which dynamically displays the most frequently submitted words from audience responses in a visual cloud format. Words with higher response frequency appear larger and more prominent, allowing quick identification of dominant ideas within a group discussion. This feature supports rapid aggregation and visualization of participant input, making it valuable for brainstorming and collective reflection activities in educational settings.

PRACTICAL IMPLEMENTATION AND METHODS

Research design and participants

The study employed a quasi-experimental design and was conducted during the 2024–2025 academic year at Samarkand State Pedagogical Institute. Two third-year undergraduate groups (n = 25 each) participated in the study. The groups were formed according to the existing academic structure, and no substantial differences in academic performance were observed prior to the intervention.

The experimental group integrated Mentimeter WordCloud during the introductory stage of lessons, whereas the control group received traditional lecture-based instruction combined with oral questioning. The intervention lasted one month and included four instructional sessions.

Research methods and instruments

The research employed a theoretical analysis of literature related to interactive learning and digital pedagogy, alongside a quasi-experimental comparison of instructional approaches between experimental and control groups. To evaluate student engagement and satisfaction, a post-lesson survey based on a 5-point Likert scale was administered. The collected data were analyzed using descriptive statistical methods, focusing on the comparison of mean performance indicators between the two groups.

Lesson design and digital workflow

In the experimental group, each lesson began with an open-ended question entered into the Mentimeter WordCloud slide. Students submitted responses via personal devices (smartphones or tablets). The platform collected responses in real time and automatically calculated word frequency.

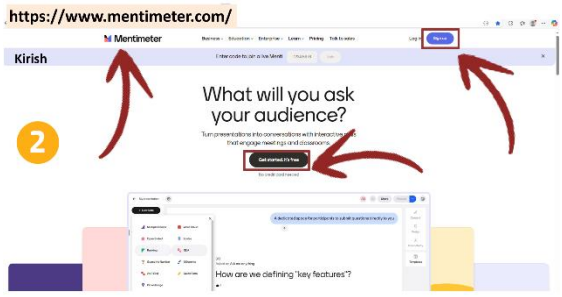

Fig. 1. General overview of the Mentimeter platform interface and the registration process for creating interactive presentations

The resulting WordCloud visualization dynamically displayed the most frequently repeated words, with word size corresponding to response frequency. The instructor then facilitated discussion based on the visualization, identifying dominant ideas and clarifying conceptual understanding.

In the control group, the same topic was introduced through conventional explanation and oral discussion without digital visualization tools.

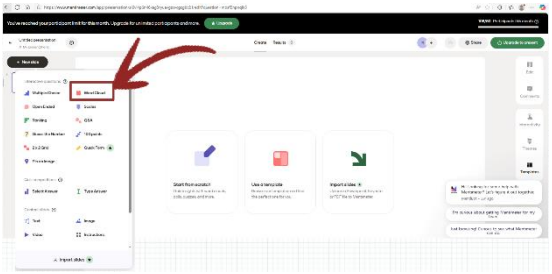

Fig. 2. Mentimeter platform interface demonstrating the selection of the WordCloud question type for creating interactive classroom activities

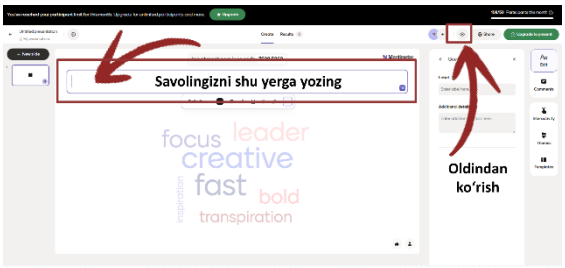

Fig. 3. Interface of the Mentimeter WordCloud slide illustrating the entry of an open-ended question to collect student responses during the introductory stage of the lesson

3. Results and discussion

Quantitative results

At the end of the intervention, both groups completed the same achievement test. The mean score of the experimental group was 4.5 (on a 5-point scale), while the control group obtained a mean score of 3.8. A t-test analysis indicated a statistically significant difference between the groups ($p < 0.05$). These findings suggest that the integration of Mentimeter WordCloud may have contributed to improved academic performance compared to traditional instruction.

Qualitative results

Survey results revealed that 92% of students in the experimental group perceived the lesson format as engaging and interactive, while 88% reported that the tool facilitated effective expression of their ideas. Interview responses further indicated that students found it easier to maintain attention during interactive lessons and reported better retention of key concepts compared to traditional classroom settings.

Table 1 presents a comparative overview of survey indicators between the experimental and control groups.

Table 1

Student Survey Results

Evaluation Indicator	Experimental Group (%)	Control Group (%)
The lesson was interesting	92	65
Opportunity to express own ideas	88	70
The topic was well understood	90	75
Active participation in class	85	60

Discussion

The findings of this study indicate that the structured integration of interactive digital tools can positively influence student engagement and learning outcomes. In particular, the visualization of collective responses through the WordCloud feature and the possibility of anonymous participation appeared to encourage broader student involvement, including those who might remain passive in traditional classroom environments.

From a cognitive perspective, organizing ideas through keyword-based visualization may support conceptual structuring and knowledge consolidation. The collective visual representation enabled students to compare their own understanding with that of their peers, thereby stimulating reflection and deeper processing of the material.

Compared to conventional lecture-based approaches, the interactive format was associated with higher levels of reported motivation and participation. However, the effective implementation of such technologies requires instructors to adopt facilitative roles, guiding discussion and interpreting real-time input within a structured pedagogical framework.

Several practical limitations should be considered, including the requirement for stable internet connectivity, additional preparation time, and potential information overload in large groups. Therefore, the pedagogical effectiveness of interactive visualization tools depends largely on thoughtful instructional design and teacher methodological competence.

Limitations and future research

This research was conducted within a single institution and over a limited time period. Future research may examine the effectiveness of WordCloud-based interaction across different disciplines, age groups, and cultural contexts. Further investigation into the integration of additional Mentimeter functionalities, such as ranking and quiz formats, may provide deeper insight into the broader pedagogical potential of interactive digital platforms.

4. Conclusion

The findings of this research indicate that the Mentimeter WordCloud feature can serve as an effective interactive tool for organizing Uzbek language instruction in higher education. The integration of real-time visualization supported increased student engagement, facilitated conceptual understanding, and encouraged collaborative discussion.

The results provide empirical support for the pedagogical integration of interactive digital technologies in language education and offer practical guidance for their structured implementation in university classrooms. The use of WordCloud-based activities enables instructors to design more engaging, participatory, and outcome-oriented lessons.

Future research may expand this approach to other academic disciplines and explore the long-term impact of interactive digital tools on learning performance and student motivation.

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Investigation of the thermal stability of the compositions of thermoset-based, anti-friction, wear-resistant polymer composite materials

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Abstract: This article shows the thermal stability of an antifriction, wear-resistant polymer composite material developed for the drum spikes of machines used for cleaning fine particles from cotton. The obtained samples were tested using STA200 thermogravimetric and differential thermal analysis equipment in the temperature range of 25-600 °C. The article discusses how properties vary depending on the filler type and its mass fraction. It also highlights that the resulting materials can be used as coatings for machine parts, potentially extending their service life due to their wear-resistant properties. A key advantage of the proposed material is that the application of composite polymer coatings can simplify the repair processes of structures, thereby achieving economic efficiency.

Keywords: antifriction-wear-resistant, polymer material, composite, thermal stability, thermogravimetric analysis, differential thermal analysis, antifriction material, drum spikes

1. Introduction

It is well known that modern machinery, technology, and mechanisms, including the technolog ical equipment used in the cotton industry, must possess the required performance and operational reliability. Along with improving the design of this equipment to maintain productivity and preserve fiber quality, the targeted application of new, highly effective anti-friction, wear-resistant composite polymer materials is considered one of the most pressing innovative scientific and technical challenges awaiting a solution**.** In particular, the materials used as friction pairs in technological equipment for cleaning cotton of fine particles must simultaneously possess a number of important properties, such as wear resistance, mechanical strength, and thermal stability [1, 2]. In this context, applying a coating of anti-friction, wear-resistant polymer composite (AWPC) material and optimizing operating mode parameters are currently essential tasks.

The use of anti-friction, wear-resistant polymer composite materials (AWPCM) based on thermosetting epoxy resins is advisable as a solution to these problems.

2. Research methodology

The expediency of structuring methods, which allow for the rational use of local raw and energy resources, has been substantiated as an effective type of modification for heterocomposite polymer materials used in the spiked working parts of cylindrical ginning drums for loosening and cleaning raw cotton [3, 4]. For the research, when preparing coating samples from anti-friction, wear-resistant polymer composite materials, composites based on the thermosetting binder epoxy resin ED-20 and fillers from local raw materials - kaolin (AKF-78), technical carbon, and fiberglass - were selected, along with a hardener, and samples were obtained in various mass parts (Table 1).

From the polymer composite materials prepared based on the compositions proposed above, coatings were obtained by roll-coating the anti-friction, wear-resistant polymer composite onto the surface of ST4 grade steel. The thermal stability of the resulting coatings was studied.

Table 1

Composition of polymer materials resistant to antifriction-wear

Composition	Function	Mass Part
Epoxy-dian resin (ED-20)	Binder	100
E-type fiberglass	Reinforcement (filler)	2
Kaolin AKF-78	Filler	35
Technical carbon	Modifier	3.5
Dibutyl phthalate (DBP)	Plasticizer	10

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Polyethylenepolyamine (PEPA)	Hardener	8

.**Methods**

To assess the thermal properties of the selected anti-friction, wear-resistant polymer composite material sample, **STA200** brand thermogravimetric differential thermal analysis (DTA) equipment was used.

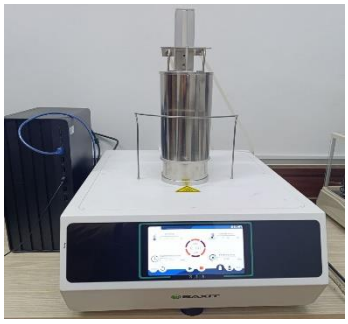

Fig. 1. STA 200 thermogravimetric differential thermal analysis (DTA)

This is a combined testing device capable of simultaneously performing thermogravimetric analysis (TGA) and differential thermal analysis (DTA), a method that rapidly measures how the mass of a material changes with temperature [5].

The evaluation of thermal properties, which are important for coatings, is conducted based on the composition and mass of the antifriction, wear-resistant polymer material under investigation. During the research, the obtained sample was heated from room temperature to 600 °C at a rate of 10 °C/min. Nitrogen (N2) gas was used as an inert medium at a flow rate of 40 ml/min. For the analysis, a 10-20 mg sample was placed in an alumina crucible. The mass change and thermal resistant to antifriction-wear 25-600 °C.

3. Results and discussion

One of the main factors ensuring the effective operation of antifriction-wear-resistant polymer composite materials based on reactoplastic under conditions of friction or abrasive wear is their thermal stability.

To determine the thermal stability of our samples, the experiment was conducted under real conditions at room temperature. 2 grams of the prepared samples were crushed, placed in a special container, and the result was obtained for 20 minutes.

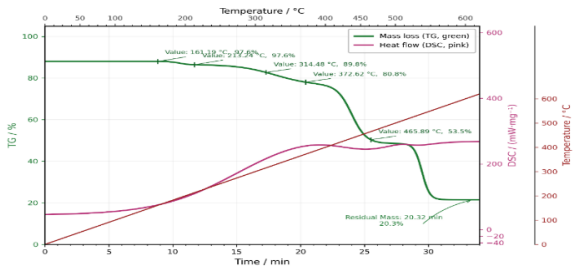

Fig. 2. Thermogravimetric and differential thermal analysis of the recommended sample

Analysis of the TGA curve shows that the thermal decomposition of the polymer composite material occurs in several consecutive stages (Fig. 2). Each stage reflects changes in the physicochemical properties characteristic of the material's constituent components (Table 2).

Table 2

Stage-by-stage analysis of TGA and DTA results

Stage	Temperature	Mass %	Loss %	Change in physicochemical properties
1	25-160	100 → 97.6	~2.4	Release of physically bound moisture and volatile components
2	160-314	97.6 → 89.8	~7.8	Initial thermal stability limit of the polymer matrix; onset of structural softening
3	314-372	89.8 → 80.8	~9.0	Onset of main polymer chain degradation
4	372-466	0.8 → 53.5	27.3	Acceleration of the degradation process
5	466-600	3.5 → 22-23	31	Almost complete degradation of organic components; residual mass - inorganic fillers

The analysis results show that in the first stage, a 2.4% decrease in sample mass was observed in the temperature range from 25 °C to 160 °C. This phenomenon is explained by the evaporation of adsorbed moisture from the sample. At this stage, no significant changes are observed in the main structure of the material[6].

In the second stage (160-314 °C), the mass decreased from 97.6% to 89.8%. This stage defines the initial thermal stability limit of the polymer matrix and is characterized by the onset of structural softening processes in the binder phase. It is important to note that the material's operational properties are maintained up to this temperature range.

In the third stage (314-372 °C), a more significant decrease in the sample's mass is observed (down to 80.8%). This stage corresponds to the beginning of the main decomposition process of the polymer chains [8].

In the fourth stage (372-466 °C), the decomposition process intensifies, and the sample mass decreases to 53.5%. In the fifth and final stage (466-600 °C), the residual mass was 22-23% as a result of the almost complete decomposition of the organic components. This residue confirms the presence of heat-resistant mineral or inorganic fillers.

Differential Thermal Analysis (DTA) Results.

Analysis of the DTA curve revealed several characteristic thermal effects:

Heat Absorption Process (80-150 °C): A weak endothermic peak was observed in this temperature range. This effect is attributed to the evaporation of moisture and low-boiling-point volatile substances present in the sample. The heat consumption is relatively small and does not significantly affect the material's structure.

Thermal Transition Process (280-350 °C): Within this range, an intensification of the thermal effect was observed. This indicates the glass transition (Tg) of the polymer matrix and the onset of initial decomposition processes. This temperature range is in full agreement with the TGA results.

Heat Release Process (above 400 °C): At these temperatures, strong exothermic processes were recorded. These are explained by the oxidation and intensive decomposition of the organic components. Such effects are characteristic of wear-resistant filler components [9].

Discussion

The results obtained indicate that the selected anti-friction, wear-resistant polymer composite material possesses sufficient thermal stability in the temperature range up to 300°C. This parameter is fully adequate for the actual operating conditions of the spiked drums in machines that clean cotton of fine impurities, as the temperature during the friction process on the drum spikes in these devices typically does not exceed 80-150°C.

A residual mass of 22-23% confirms the presence of heat- and wear-resistant mineral or inorganic fillers in the composition. These fillers play a crucial role in maintaining the material's mechanical strength and wear resistance during the friction process [10].

The small endothermic effect (80-150°C) recorded in the DTA results indicates the absence of excess moisture in the material, which in turn suggests its good moisture resistance. The exothermic processes observed at temperatures above 400°C can only occur under extremely high-temperature conditions (such as a fire or emergency), and such temperatures are not reached under normal operating conditions.

Furthermore, the research results show that reinforcing polymer composite materials derived from thermosetting resins with local raw materials and mineral fillers significantly enhances their thermal stability [11,12].

4. Conclusion

The research indicates that the resulting antifriction, wear-resistant polymer composite materials meet the operational requirements for the spikes of cotton cleaning machines, maintaining thermal stability up to 300°C. The 22-23% residual mass at the end of thermal decomposition corresponds to the inorganic fraction of kaolin and carbon black.

The correlation between the TGA and DTA results confirms the reliability of the experiments. Optimizing the composition and mass fractions of the filler materials achieved a 15-20% increase in thermal stability. This antifriction, wear-resistant composite polymer material, developed using local raw materials and waste, is an effective solution for ensuring equipment reliability and fiber quality in the cotton industry.

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Methodology for improving software and didactic support aimed at developing programming competence among future engineers

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Abstract: In the context of digitalization of education, the creation of an integrated system that combines modern software development technologies, a didactic model, and a methodology for their implementation in the educational process is of particular importance. The developed didactic model for the course "Information Technologies in Technical Systems" includes target, organizational-methodological, content-related, and diagnostic blocks, and is based on competence-based, system-activity, spiral, and modular approaches. It implements the principles of adaptability, visualization, interactivity, and interdisciplinarity, and also ensures the objectivity of assessment through a system of criteria and indicators reflecting motivation, independence, technical accuracy, creativity, and knowledge integration.

Keywords: digitalization, education, modern technologies, didactic model, methodology, information technology, competence

Методика совершенствования программно- дидактического обеспечения развитвающая компетентность в программирования будущих инженеров

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Аннотация: В условиях цифровизации образования особое значение приобретает создание целостной системы, которая объединяет современные технологии разработки программного обеспечения, дидактическую модель и методику их внедрения в учебный процесс. Разработанная дидактическая модель для курса "Информационные технологии в технических системах" включает в себя целевой, организационно методологический, содержательный и диагностический блоки и опирается на компетентностный, системно деятельностный, спиральный и модульный подходы. Она реализует принципы адаптивности, наглядности, интерактивности и междисциплинарности, а также обеспечивает объективность диагностики за счёт системы критериев и индикаторов, отражающих мотивацию, самостоятельность, техническую точность, креативность и интеграцию знаний.

Ключевые слова: цифровизация, образования, современные технология, дидактический модель, методика, информационная технология. Компетентностность

1. Введение

В условиях стремительной цифровой трансформации всех сфер деятельности особую значимость приобретает совершенствование методики обучения программированию в инженерных специальностях. Быстрое развитие технологий требует от образовательных учреждений регулярного обновления учебных планов и внедрения современных подходов, ориентированных на практическое применение знаний [**Ошибка! Источник ссылки не найден.**]. Использование инновационных программно-дидактических средств обеспечивает не только более высокое качество усвоения материала, но и формирует у студентов навыки критического анализа, самостоятельного поиска решений и эффективного взаимодействия в команде. Всё это способствует подготовке конкурентоспособных специалистов, способных успешно работать в условиях цифровой экономики и вносить вклад в развитие высокотехнологичных отраслей.

В последние годы в Республике Узбекистан реализуются стратегические проекты, направленные на формирование цифрового общества и модернизацию системы высшего образования. Особое внимание уделяется подготовке инженерных кадров, способных эффективно использовать современные информационно-коммуникационные технологии. Важным направлением становится цифровизация образовательного процесса, внедрение электронных платформ и обновление методик обучения, ориентированных на практическое применение знаний. Таким образом актуальной задачей является совершенствование программно-дидактического обеспечения, обеспечивающего развитие

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компетентности в программировании у будущих инженеров.

В условиях стремительной цифровой трансформации всех сфер деятельности особую значимость приобретает совершенствование методики обучения программированию в инженерных специальностях. Быстрое развитие технологий требует от образовательных учреждений регулярного обновления учебных планов и внедрения современных подходов, ориентированных на практическое применение знаний [**Ошибка! Источник ссылки не найден.**]. Использование инновационных программно-дидактических средств обеспечивает не только более высокое качество усвоения материала, но и формирует у студентов навыки критического анализа, самостоятельного поиска решений и эффективного взаимодействия в команде. Всё это способствует подготовке конкурентоспособных специалистов, способных успешно работать в условиях цифровой экономики и вносить вклад в развитие высокотехнологичных отраслей.

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Разрешение выявленных противоречий предполагает разработку и внедрение программно-дидактического обеспечения, которое объединяет в себе: дидактическую модель, основанную на компетентностном подходе; цифровые инструменты визуализации, диагностики и адаптации учебного процесса; средства автоматизированного мониторинга и обратной связи, обеспечивающие объективную оценку уровня развития компетентности и поддержку индивидуальных образовательных траекторий студентов. Проблема развития компетентности в программировании у студентов инженерных направлений широко обсуждается в современной педагогической науке. Компетентностный подход, зафиксированный в стратегических документах и образовательных стандартах, рассматривается, как ключевая методологическая основа модернизации высшего образования. Его сущность заключается в ориентации на результат — формирование у обучающихся способности применять знания, умения и личностные качества в профессиональной деятельности [2].

Объект исследования — образовательный процесс подготовки будущих инженеров, направленный на развитие компетентности в программировании в условиях цифровой образовательной среды.

Предмет исследования — программно-дидактическое обеспечение, включающая в себя цифровые инструменты и дидактическую модель, используемое для развития компетентности в программировании у будущих инженеров.

2. Методология исследования

Методы исследования**.** Для решения поставленных задач использовались следующие методы: Теоретические — анализ философской, психолого-педагогической и методической литературы; систематизация научных подходов; теоретическое моделирование. Диагностические — анкетирование, тестирование, экспертная оценка и самооценка студентов. Эмпирические — наблюдение, проведение педагогического эксперимента, обобщение опыта внедрения цифровых решений в инженерное образование. Статистические — количественная и качественная обработка данных, применение t-критерия Стьюдента, корреляционного анализа и методов визуализации результатов. Для обеспечения методической целостности и научной обоснованности работы определена методологическая основа исследования. Методологическую основу исследования составили: Компетентностный подход, определяющий ориентацию образовательного процесса на развитие у студентов способности применять знания и умения и навыки в профессиональной деятельности; Системный подход, позволяющий рассматривать процесс развития компетентности в программировании как целостную систему, включающую цели, содержание, методы, средства и результаты; Деятельностный подход, делающий акцент на активной позиции обучающихся и развитии у них практических навыков программирования; Положения теории поэтапного формирования умственных действий, обеспечивающей постепенное освоение программных и алгоритмических знаний; Современные концепции цифровой педагогики, раскрывающие возможности использования цифровых образовательных ресурсов и инструментов для индивидуализации обучения [3].

Научная новизна исследования заключается в следующем:

Определены дидактические возможности программно-дидактического обеспечения, обеспечивающие развитие компетентности в программировании будущих инженеров.

Усовершенствована дидактическая модель, развивающая компетентность в программировании будущих инженеров.

Уточнено и обновлено содержание программно-дидактического обеспечения с учётом цифровой образовательной среды.

Экспериментально подтверждена эффективность внедрения, разработанного программно-дидактического обеспечения в учебный процесс.

Практические результаты исследования. Полученные научные выводы нашли отражение в образовательной практике и обеспечили конкретные результаты внедрения: разработано и внедрено программно-дидактическое обеспечение, включающее электронный учебник, цифровые ресурсы и платформу в учебный процесс инженерных направлений; подготовлены методические рекомендации для преподавателей технических дисциплин по использованию цифровой образовательной среды для процесса развитии компетентности в программировании; создана и апробирована

дидактическая модель, способствующая развитию алгоритмического мышления и практических навыков программирования у студентов инженерных направлений.

Методика

Подготовка будущих специалистов во многом зависит от эффективного внедрения цифровых технологий. Для этого необходимо повышение квалификации и переподготовки учителей в системе непрерывного образования, чтобы они могли использовать современные ИКТ в учебном процессе. Особое внимание нужно уделять созданию современной образовательной среды, включению традиционных и инновационных методов, а также развитию медиакомпетентности педагогов. В качестве актуальных задач выделяются разработка электронных учебников, расширение дистанционного обучения и использование компьютерного моделирования. Таким образом, необходим системный подход к цифровизации образования, направленный на формирование конкурентоспособных специалистов [4].недостаточный уровень

Рассматривая проблему формирования компетентности у будущих инженеров следует отметить недостаточный уровень подготовки студентов и необходимость адаптации учебных программ к требованиям индустрии. Необходима система подготовки, направленная на развитие профессиональных навыков, повышение уровня компетентности в области программирования [6].

Далее для рассмотрения современных образовательных платформ и программных средств ниже представлена сравнительная таблица 1., в которой систематизированы их ключевые характеристики. Она отражает сильные и слабые стороны каждого решения, а также демонстрирует перспективные возможности развития и потенциальные угрозы, выявленные в ходе SWOT-анализа.

Таблица 1

SWOT-анализ программного обеспечения, применяемого в процессе обучения программированию

Программное обеспечение	Сильные стороны	Слабые стороны	Возможности	Угрозы
Онлайн-обучение и курсы (Coursera, Udemy, edX, Академия Хана)	Доступность обучения независимо от географического положения; широкий выбор курсов по различным тематикам и уровням; гибкость в выборе темпа освоения материала; наличие сертификатов от ведущих университетов и компаний	Ограниченное живое взаимодействие с преподавателем; риск снижения мотивации у студентов; недостаточно глубокая проверка знаний	Рост интереса к дистанционному обучению; интеграция с корпоративными программами; развитие интерактивных форматов и внедрение ИИ-поддержки	Усиление конкуренции со стороны бесплатных ресурсов; технические трудности и ограниченный доступ к интернету у части пользователей; появление новых платформ с более выгодными условиями
Обучение программированию (Codecademy, freeCodeCamp)	Практическая направленность и интерактивность; наличие бесплатных и платных курсов с реальными проектами; регулярное обновление контента в соответствии с современными технологиями	Высокие требования к самоорганизации; ограниченная поддержка со стороны преподавателей; сложность для начинающих без базовых знаний	Рост интереса к профессиям в сфере IT; внедрение геймификации и ИИ для адаптивного обучения; сотрудничество с компаниями для трудоустройства выпускников	Быстрое устаревание технологий; конкуренция со стороны офлайн-курсов и университетов; риск появления низкокачественного или мошеннического контента
Системы управления обучением (LMS) (Moodle, Google Classroom, Canvas)	Централизованное управление учебным процессом; интеграция с другими образовательными сервисами; поддержка различных форматов контента и оценивания	Сложности внедрения и настройки; необходимость технической поддержки и обучения персонала; возможные риски для безопасности данных	Расширение применения дистанционного и гибридного обучения; использование аналитики и ИИ для персонализации;	Конкуренция между платформами; быстрые изменения образовательных стандартов; вероятность технических сбоев и уязвимостей

			развитие интерактивных и коллаборативных функций	
Инструменты для дистанционных занятий и видеоконференций (Zoom, Microsoft Teams, TrueConf)	Удобство проведения онлайн-занятий и встреч; высокое качество аудио- и видеосвязи; интеграция с календарями и образовательными платформами	Зависимость от стабильного интернет-соединения; ограничения бесплатных версий; возможные проблемы с безопасностью и конфиденциальностью	Рост популярности гибридного обучения; разработка новых функций для интерактивности; интеграция с ИИ для автоматизации и анализа занятий	Конкуренция со стороны новых технологий (VR/AR); риски утечки данных; «усталость» пользователей от постоянных видеоконференций
Образовательные AI-приложения (Squirrel AI, автоматизация проверки заданий)	Персонализированный подход к обучению; автоматизация рутинных задач (проверка, оценка); возможность анализа больших массивов данных об успеваемости	Высокая стоимость внедрения; необходимость качественных обучающих данных; риск ошибок и несправедливых оценок	Развитие адаптивного и инклюзивного обучения; интеграция с другими образовательными системами; создание новых форматов обучения на основе ИИ	Этические вопросы и опасения по поводу приватности; недоверие к автоматическим оценкам; быстрое устаревание технологий искусственного интеллекта

SWOT-анализ показывает, что каждое программное средство имеет свои сильные и слабые стороны, а также перспективы развития и риски применения в образовательной среде. Однако сами по себе эти инструменты не решают задачу подготовки специалистов: их ценность в том, что, когда они становятся частью учебного процесса, они помогают развивать профессиональные компетенции, необходимые будущему специалисту. В этом контексте особенно важны исследования, посвящённые требованиям к будущим инженерам. Так, Давыдовская В.В. и Ефимчик И.А. [6] отмечают, что студенты строительных специальностей должны овладеть навыками решения технических задач, необходимых для будущей профессиональной деятельности. Речь идёт о правильном определении машиноемкости строительных процессов, расчёте потребности в рабочих, машинах, механизмах и материалах, подсчёте объёмов работ и составлении технологических операций. Кроме того, инженеры должны уметь обоснованно выбирать методы выполнения процессов и справляться с сопутствующими задачами. Сегодня такие расчёты и анализы преимущественно выполняются с использованием компьютеров и специализированных прикладных программ — Excel, Maple, MathCAD, MATLAB.

Современная подготовка инженеров предполагает системный и комплексный подход к формированию их профессиональных компетенций в области программирования. Одним из ключевых условий достижения этой цели является разработка специализированного программно-дидактического обеспечения, которое способствует не только усвоению знаний, но и формированию практических навыков и умений, необходимых для решения прикладных инженерных задач с использованием средств программирования.

Технологии создания подобного обеспечения охватывают широкий спектр направлений: от выбора оптимальных языков программирования и инструментов разработки до внедрения интерактивных методик обучения и систем автоматизированного контроля качества знаний студентов. Такой комплексный подход обеспечивает не только повышение эффективности образовательного процесса, но и его соответствие современным требованиям цифровой экономики.

В условиях стремительного развития цифровой экономики Республика Узбекистан предпринимает масштабные шаги по модернизации системы образования. Главная цель этих преобразований заключается в подготовке специалистов нового поколения, способных уверенно применять современные информационные технологии и программные средства в профессиональной деятельности. Важным ориентиром в этом направлении стал Указ Президента Республики Узбекистан от 5 октября 2020 года № УП-6079 «Об утверждении Стратегии "Цифровой Узбекистан — 2030"». В соответствии с данным документом реализуется комплекс мероприятий, направленных на цифровизацию всех сфер, включая образование. Особое внимание уделяется подготовке квалифицированных кадров в области информационных технологий, внедрению современных образовательных практик и созданию инновационных программно-дидактических

средств, способствующих развитию компетентности в программировании [7].

Одной из важных задач цифровизации образования является создание электронных образовательных ресурсов, цифровых данных, электронных энциклопедий, интерактивных обучающих систем, средств автоматизированного контроля знаний студентов, а также единого комплекса программно-методических материалов, включающего электронные учебники, тренажёры и виртуальные лаборатории на образовательных порталах. Современные вычислительные технологии, внедряемые в учебный процесс, становятся основой для формирования цифровых образовательных платформ в учебных заведениях [8]. При обучении программированию с использованием цифровых образовательных платформ главное значение имеет разработка и внедрение специализированного программного обеспечения, методических материалов, электронных учебников, а также интерактивных тренажёров и виртуальных стендов. Учебные материалы, представленные через платформу, должны быть доступными и понятными для студентов. Их структура должна обеспечивать удобство восприятия и последовательное усвоение содержания. Рекомендуемые ресурсы включают чёткие определения, ключевые термины и примеры, способствующие эффективному проведению практических и лабораторных занятий. Организация лекций, практических и лабораторных занятий по дисциплине «Информационные технологии в технических системах» с использованием цифровой платформы открывает широкие возможности для формирования компетентности студентов. Применение платформы позволяет отказаться от дорогостоящего оборудования, печатных учебников и традиционных наглядных материалов. Лабораторные работы могут выполняться в формате анимаций и интерактивных демонстраций, что обеспечивает детальную визуализацию процессов и алгоритмов.

Кроме того, платформа создаёт условия для самостоятельного освоения материала в удобное время, включая домашнюю работу и дистанционное обучение, сохраняя при этом методическую целостность курса. Организация учебного процесса с использованием обучающих платформ имеет существенные преимущества по сравнению с традиционными методами. Современный формат подачи материалов позволяет преподавателю эффективно структурировать и обновлять содержание курса, а студенты получают возможность многократного просмотра и интерактивного взаимодействия с контентом, что способствует более глубокому усвоению знаний. Применение мультимедийных средств — видео, аудио и анимации — делает занятия наглядными и интересными, а сетевые технологии обеспечивают массовый доступ к ресурсам и позволяют обучать студентов из разных групп и аудиторий одновременно. Платформа поддерживает дистанционный и смешанный форматы, создавая гибкость образовательного процесса, а встроенные инструменты контроля знаний — тесты, задания и аналитические отчёты — дают возможность отслеживать индивидуальный прогресс. Дополнительным преимуществом является персонализация обучения: платформа учитывает уровень подготовки и особенности каждого студента, что делает процесс формирования компетенций более эффективным.

Формирование практических навыков поддерживает блок интерактивных инструментов, включающий задания разного уровня сложности, тестирование, визуализацию алгоритмов и пошаговые инструкции. Вариативность заданий позволяет адаптировать процесс под уровень подготовки студентов, а визуальные средства способствуют лучшему пониманию логики программ. Эффективность работы с контентом определяется качеством интерфейса: адаптивная мобильная версия, удобная навигация и синхронизация данных создают условия для непрерывного обучения. Продуманная структура снижает когнитивную нагрузку и формирует устойчивые учебные привычки. Контроль усвоения материала реализуется через средства оценки — тесты, анализ результатов и обратную связь. Это помогает преподавателю корректировать процесс, а студентам осознавать собственные достижения. Завершающий блок — коммуникация: встроенные справочные материалы, FAQ и чаты обеспечивают постоянное взаимодействие, формируют учебное сообщество и поддерживают мотивацию. Все блоки образуют замкнутый цикл обучения: от получения знаний к их закреплению, оценке и корректировке траектории. Модульная структура обеспечивает гибкость и адаптивность системы, гарантируя методическую целостность и устойчивое развитие компетентности в программировании.

Таким образом, архитектурная модель платформы интегрирует образовательный контент, интерактивные инструменты, средства оценки и коммуникации в единый технологический комплекс, поддерживающий непрерывный цикл обучения. Однако архитектура задаёт лишь технические возможности; их реализация требует педагогической логики, которая отражается в дидактической модели, описывающей цели, содержание, методы и средства обучения.

3. Результаты и обсуждение

Эффективное внедрение программно-дидактического обеспечения в инженерное образование требует соблюдения комплекса методических условий, обеспечивающих дидактическую целостность, технологическую реализуемость и соответствие государственным образовательным стандартам.

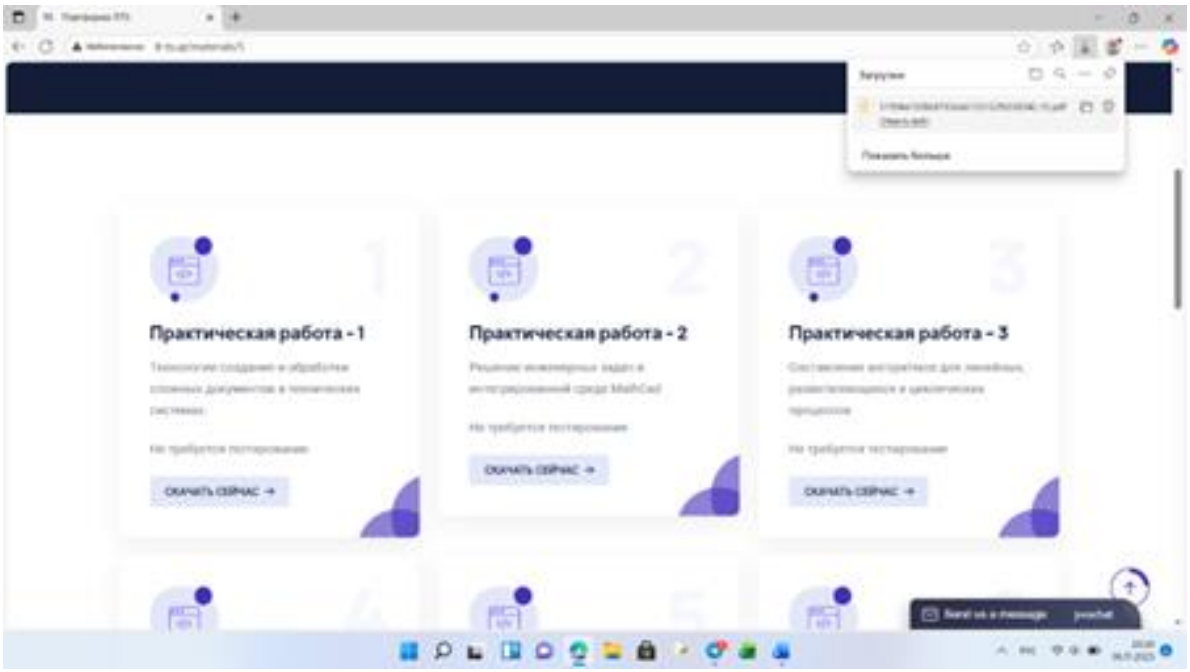

Рис. 1. Загрузка нужной практической работы из платформы

Эти условия охватывают организационно-педагогические, технологические и содержательные аспекты, формируя единую систему поддержки учебного процесса. Программно-дидактическое обеспечение должно быть встроено в учебный процесс как функциональный компонент дидактической системы. Это предполагает соответствие цифровых инструментов целям и задачам дисциплины, их способность реализовывать ключевые функции обучения — мотивацию, визуализацию, контроль, рефлексию и проектную деятельность.

Домашнее задание: просмотреть видео-урок по практической работе в платформе “ITTS”. Ознакомиться с требованиями к оформлению практической работы и чек-листом для оценки практической работы в “ITTS”. Подготовить отчёт по практической работе в соответствии с требованиями и выполненными вариантами заданий. Быть готовым к опросу.

Результат

Методика совершенствования программно-дидактического обеспечения, интегрированная в цифровую образовательную среду для развития компетентности в программировании у студентов инженерных направлений, в ходе проведённых исследований была оценена по критериям эффективности: самостоятельность, креативность, рефлексивность, коммуникативность.

С учётом данных критериев были определены следующие уровни оценки: 5 — высокий, 4 — средний, 3 — низкий.

На основе указанных критериев и уровней были получены как предварительные результаты опытно-экспериментальных работ, так и итоговые результаты на заключительном этапе. Полученные данные представлены ниже и подвергнуты сравнительному и статистическому анализ.

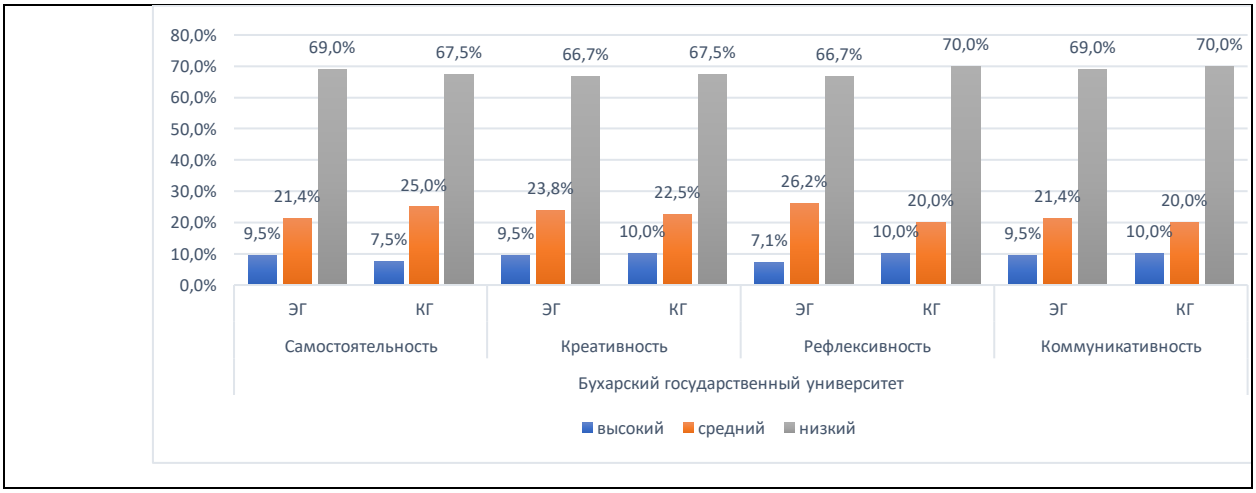

Рис. 2. Полученные результаты по процентным показателям усвоения отражены на следующих диаграммах

В исследованиях по теме “Методика совершенствования программно-дидактического обеспечения, интегрированного в цифровую образовательную среду, для развития компетентности в

программировании у студентов инженерных направлений" были представлены средние показатели усвоения по критериям, определяющим эффективность, а также диаграммы результатов эффективности.

4. Заключение

Таким образом, результаты третьей главы убедительно демонстрируют переход от равных стартовых условий к статистически значимым различиям, подтверждающим результативность предложенной методики. Она обеспечивает повышение качества усвоения знаний, развитие ключевых компетенций в программировании и снижение доли студентов с низким уровнем подготовки. Наибольший эффект методика оказала на развитие рефлексивности, что свидетельствует о её способности формировать навыки анализа, самооценки и критического мышления. В целом проведённое исследование подтверждает научную обоснованность и практическую ценность разработанной методики, которая может быть рекомендована для внедрения в образовательный процесс инженерных направлений.

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Influence of a truncated conical elastomeric element on rotor vibrations in a bearing support

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Abstract: The paper investigates the influence of a truncated conical elastomeric element embedded in a bearing support on the vibrational behavior of a rotor system. A dynamic model of the "rotor–bearing–support" system is considered, taking into account the elastic and damping properties of the elastomeric layer and the asymmetry of the rotor's center of mass. Based on Lagrange's equations of the second kind, an equation of forced vibrations is obtained, and numerical modeling of amplitude–frequency and transient characteristics is performed. It is shown that the use of a conical elastomer leads to a reduction in resonance amplitudes, a shift in the critical frequency, and an increase in the dynamic stability of the system.

Keywords: rotor system, bearing support, elastomeric element, truncated cone, rotor vibrations, damping, critical frequency

Влияние усечённого конического эластомерного элемента на вибрации ротора в подшипниковой опоре

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Аннотация: В работе исследуется влияние усечённого конического эластомерного элемента, встроенного в подшипниковую опору, на вибрационное поведение роторной системы. Рассмотрена динамическая модель системы «ротор–подшипник–опора», учитывающая упругие и демпфирующие свойства эластомерного слоя и асимметрию центра масс ротора. На основе уравнений Лагранжа II рода получено уравнение вынужденных колебаний и выполнено численное моделирование амплитудно-частотных и переходных характеристик. Показано, что применение конического эластомера приводит к снижению резонансных амплитуд, смещению критической частоты и повышению динамической устойчивости системы.

Ключевые слова: роторная система, подшипниковая опора, эластомерный элемент, усечённый конус, вибрации ротора, демпфирование, критическая частота

1. Введение

Вибрации роторов и подшипниковых опор в течение последних десятилетий остаются одной из центральных проблем роторной динамики. Современные исследования показывают, что даже при отсутствии явных дефектов геометрии в подшипниках возникают переменные контактные напряжения и колебания жёсткости, приводящие к сложной динамике системы «ротор-подшипник» [1, 2]. Эти эффекты усиливаются при повышении частоты вращения и появлении асимметрии масс ротора, что особенно характерно для технологических машин, работающих в тяжёлых режимах.

В работе Zhou и соавт. показано, что использование магнитно-реологических и улучшенных контактных сред позволяет снижать подповерхностные повреждения и продлевать срок службы поверхностей трения [3]. Sawalhi и др. разработали объединённую динамическую модель «шестерня-подшипник», продемонстрировав тесную связь между повреждениями зубчатых передач и локальными дефектами подшипников, а также их совместное влияние на вибрационный спектр системы [4]. Эти результаты подчёркивают, что подшипник следует рассматривать не как изолированный узел, а как элемент сложной динамической системы.

Ряд классических работ посвящён именно влиянию геометрических и распределённых дефектов на вибрации подшипников. Так, Sunnersjo показал, что волнистость дорожек качения и отклонения формы вызывают характерные вибрационные компоненты, которые могут служить диагностическим признаком износа [1]. Обзор Tandon и соавт. систематизирует методы вибрационной и акустической диагностики дефектов в подшипниках качения и подчёркивает важность учёта как локальных, так и распределённых повреждений при оценке состояния узла [2]. Ocak и коллеги продемонстрировали возможность оценивать

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частоты дефектов подшипников и режимы работы двигателя на основе вибрационных сигналов, что имеет значение для ранней диагностики [5].

Отдельное направление связано с влиянием конструкции опоры и упругих элементов на динамику ротора. Экспериментальные и численные исследования валов технологических машин показывают, что снижение изгиба вала и оптимизация схемы опирания позволяют уменьшить нагрузки на подшипники и повысить устойчивость вращения [6, 7]. В более современных работах внимание смещается к комбинированным опорам с упругими и демпфирующими вставками. Li и соавт. разработали нелинейную модель системы «ротор-подшипник» с упругой опорой, учитывающую сопряжённое движение несущей конструкции и подшипников; показано, что эластичная опора может существенно ослаблять нелинейные вибрации, снижать контактные нагрузки и изменять форму колебаний ротора [8].

Особый интерес представляют исследования эластомерных подшипников и опор. В ряде работ установлено, что эластомерные элементы обладают высоким внутренним демпфированием и могут эффективно гасить колебания ротора в широком диапазоне частот. Kim и соавт. выполнили нелинейный конечно-элементный анализ эластомерного подшипника для втулки вертолётного ротора, показав, что корректный выбор жёсткостных характеристик резинометаллического пакета обеспечивает требуемую податливость по нескольким степеням свободы и при этом сохраняет несущую способность узла [9]. На эту работу опирается более позднее исследование Jang и коллег, где анализируется многослойный эластомерный подшипник для втулки ротора при больших осевых нагрузках и нелинейных перемещениях; авторами приведены результаты численного моделирования и испытаний, подтверждающие, что правильно спроектированный эластомерный пакет способен обеспечить как необходимую жёсткость, так и достаточную демпфирующую способность при эксплуатации [10].

Таким образом, проведённые исследования показывают, что:

- геометрические и эксплуатационные дефекты подшипников существенно влияют на вибрации ротора [1-5];
- включение упругих опорных элементов позволяет перераспределять нагрузки и уменьшать нелинейные вибрации системы [6, 7, 8];
- эластомерные подшипниковые элементы, в том числе многослойные и специально профилированные, обладают высоким потенциалом для демпфирования и виброизоляции роторов [3, 9, 10].

При этом влияние усечённого конического эластомерного элемента именно в составе опоры подшипника, с учётом асимметрии центра масс ротора и работы в условиях переменных технологических нагрузок, в литературе освещено недостаточно. Это определяет научную новизну и актуальность настоящей работы.

2. Методология исследования

Анализ представленных литературных источников показывает, что, несмотря на обширные исследования динамики роторов и подшипниковых узлов, влияние усечённого конического эластомерного элемента, встроенного непосредственно в опору подшипника, изучено недостаточно. Имеющиеся работы посвящены либо диагностике дефектов вращающихся элементов [1-5], либо оптимизации традиционных схем опирания роторов [6, 7], либо исследованию общих свойств эластомерных опор [8-10]. Однако вопрос о том, как именно геометрия усечённого конуса, его жёсткостные характеристики и демпфирующие свойства влияют на динамику системы «ротор-подшипник» в условиях переменных технологических нагрузок, остаётся практически не раскрытым.

Учитывая это, настоящая работа направлена на решение следующей научной задачи, исследовать влияние усечённого конического эластомерного элемента на вибрационное поведение ротора и определить его эффективность в снижении амплитуды вынужденных колебаний и смещении критической скорости системы.

Для достижения цели исследования предполагалось разработать конструкцию подшипниковой опоры с усечённым коническим эластомерным элементом и определить её основные механические характеристики. Далее требовалось построить математическую модель системы «ротор-подшипник», учитывающую влияние эластомерного слоя, и получить уравнение движения ротора для последующего численного решения. Также необходимо было проанализировать амплитудно - частотные характеристики при различных значениях жёсткости и геометрии элемента, определить влияние эластомерного слоя на резонансные параметры - максимальную амплитуду, критическую частоту и скорость затухания колебаний - и, наконец, сопоставить полученные результаты с характеристиками традиционной жёсткой подшипниковой опоры. Научная новизна работы заключается в следующем:

Таким образом, постановка задачи определяет направление дальнейших исследований и обосновывает необходимость численного моделирования и анализа динамического поведения системы.

Описание конструкции усечённого конического эластомерного элемента

Подшипниковая опора, рассматриваемая в настоящем исследовании, включает в себя специальный усечённый конический эластомерный элемент, размещённый между корпусом опоры и наружным кольцом подшипника. Выбор именно такой геометрической формы обусловлен её уникальными свойствами по обеспечению переменной жёсткости, эффективного демпфирования и адаптации к динамическим нагрузкам.

Усечённый конический эластомерный элемент представляет собой деталь, внешняя и внутренняя поверхности которой образованы усечёнными конусами с различными углами раскрытия. Основными геометрическими параметрами элемента являются:

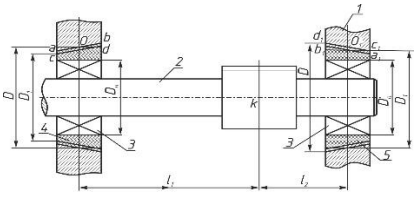

Рис 1. Общая схема установки вращающегося вала с несимметричным центром масс

где, l_1 - расстояния от первой (левой) подшипниковой опоры до центра масс вала;

l_2- расстояния от второй (правой) подшипниковой опоры до центра масс вала;

D_1 -диаметр наружной поверхности упругого элемента первой подшипниковой опоры;

D_2- диаметр наружной окружности второго упругого элемента.

D - диаметр внутренней поверхности упругих элементов

Толщина эластомерного слоя изменяется по высоте, что приводит к перераспределению жесткости при радиальных и осевых нагрузках. При увеличении нагрузки деформация происходит постепенными слоями, что добавляет системе нелинейный демпфирующий эффект.

В традиционных подшипниковых опорах жесткость практически постоянна, поэтому при проходе через критическую скорость система демонстрирует резко выраженный резонанс. Применение усечённого конического эластомерного элемента позволяет эффективно снизить вибрации ротора. Благодаря переменной жёсткости по высоте такой элемент по-разному реагирует на малые и большие нагрузки: при небольших нагрузках он обеспечивает устойчивость опоры, а при повышенных - увеличивает деформацию, уменьшая амплитуду колебаний. Нелинейные свойства эластомера обеспечивают дополнительное демпфирование за счёт внутренних потерь материала. Это приводит к снижению резонансных проявлений и смещению критической частоты в более безопасную область. Кроме того, эластомерный слой компенсирует несоосность, небольшую неуравновешенность и технологические колебания нагрузки, выполняя роль упругого виброизолятора.

Усечённая коническая форма эластомерного элемента обеспечивает ряд преимуществ по сравнению с цилиндрическими и плоскими вставками. Такая геометрия обладает большей энергоёмкостью деформации, лучше противостоит смещению и сдвиговым нагрузкам, а также обеспечивает более равномерное распределение напряжений, повышая износостойкость. Коническую вставку легко адаптировать под требуемую жёсткость, изменяя угол конуса или толщину слоя. При компактных размерах она демонстрирует высокую эффективность виброизоляции, что делает конструкцию одновременно технологичной и надёжной в эксплуатации. Математическая модель системы «ротор-подшипник» с эластомерным усечённым коническим элементом

Математическое моделирование динамических процессов в роторных системах выполняется на основе Лагранжевых уравнений II рода, что позволяет учитывать одновременно инерционные, упругие и демпфирующие свойства элементов конструкции. Такой подход особенно важен в случае применения эластомерных вставок переменной жёсткости, поскольку их характеристики зависят от геометрических параметров и действующих нагрузок.

В данной работе модель включает не только радиальное перемещение опоры, но и возможный угол поворота ротора, что обеспечивает более корректное описание динамического состояния при наличии асимметрии, эксцентриситета или дополнительных моментов.

Кинетическая энергия системы складывается из поступательной и вращательной составляющих. С учётом массы ротора mmm и его момента инерции J относительно оси вращения общее выражение приобретает вид:

$$T = \frac{1}{2}m\dot{x}^2 + \frac{1}{2}J\dot{\theta}^2$$

где

x - радиальное перемещение центра массы,

θ - угловое отклонение или поворот ротора,

$\dot{x}, \dot{\theta}$- соответствующие скорости.

Первая часть выражения отражает поступательное движение центра массы, возникающее под действием несбалансированных сил. Вторая часть представляет собой вращательную кинетическую энергию, необходимую для учёта динамики поворота ротора относительно его оси. Учет обеих составляющих позволяет сформировать полную интегральную динамическую модель, в которой переменные взаимосвязаны через уравнения движения.

Потенциальная энергия исследуемой системы обусловлена упругими деформациями двух последовательно работающих элементов: подшипника качения и эластомерного слоя, установленного между наружным кольцом подшипника и корпусом. При малых относительных перемещениях система может рассматриваться как линейно-упругая, а суммарная потенциальная энергия записывается в форме:

$$V = \frac{1}{2}(k_b + k_e)x^2$$

где:

k_b - жёсткость подшипника качения,

k_e - эквивалентная жёсткость эластомерного элемента.

x- относительное перемещение опоры.

Такое представление корректно при условии малых деформаций, когда суммарная жёсткость определяется суперпозицией отдельных вкладов. При увеличении жёсткости эластомерного слоя возрастает общий коэффициент восстановления системы, что непосредственно влияет на собственную частоту колебаний и устойчивость динамического равновесия ротора.

Эластомерный элемент выполняется в форме усечённого конуса для обеспечения управляемой деформации и возможности варьирования жёсткостных характеристик за счёт изменения геометрии. При осевом нагружении элемент работает на сжатие, и его эквивалентная жёсткость в первом приближении оценивается выражением

$$k_e = \frac{E_e \cdot A_{eff}}{h_{eff}}$$

где:

E_e - модуль упругости эластомера,

A_{eff} - эффективная площадь, зависящая от конусности,

h_{eff} - эквивалентная толщина слоя.

Для геометрии в виде усечённого конуса эффективная площадь определяется по формуле:

$$A_{eff} = \pi\frac{(d_1^2 + d_1 d_2 + d_2^2)}{3},$$

Эквивалентная толщина рассчитывается с учётом исходной толщины h_0 и поправки на угол конусности α:

$$h_{eff} = h_0 + \Delta h(\alpha)$$

что отражает реальное перераспределение деформаций по высоте элемента. Таким образом, жёсткость эластомерной втулки является функцией её геометрических параметров:

$$k_e = k_e(\alpha, h_0, d_1, d_2)$$

Это позволяет регулировать динамические свойства опоры, выбирая оптимальную форму и высоту конусного слоя под конкретный диапазон рабочих скоростей ротора.

Диссипативная функция Релея: Потери энергии в системе обусловлены двумя факторами: внутренним демпфированием подшипника и вязкоупругими свойствами эластомерного материала. Суммарный процесс диссипации описывается функцией Релея:

$$T = \frac{1}{2} c\dot{x}^2$$

где полный коэффициент демпфирования:

$$c = c_b + c_e$$

и состоит из вклада подшипника c_b и вязкого компонента демпфирования эластомера c_e.

Эластомерный слой обеспечивает преимущественную часть демпфирования системного отклика, так как полимеры обладают высоким внутренним трением и переходом части механической энергии в тепловую. Увеличение c_e обеспечивает более быстрое затухание переходных процессов ротора и значительное снижение резонансных амплитуд.

Уравнение возбуждающей силы: Основным источником возбуждения колебаний ротора является динамическая сила, возникающая при наличии эксцентриситета *e* массы *m*. При равномерном вращении ротора сила имеет гармонический характер:

$$F(t) = me\Omega^2 \sin(\Omega t)$$

где

Ω - угловая скорость вращения.

Данная сила действует на опору и является ключевым фактором появления вибраций, особенно при приближении частоты вращения к критическим значениям.

В модели предполагается отсутствие значительных нелинейных эффектов, что справедливо для малых амплитуд колебаний и жёсткой конструкции вала.

Используя выражения для потенциальной и диссипативной энергии, а также учитывая внешнюю силу, получаем лагранжеву модель динамики опоры:

$$m\ddot{x} + c\dot{x} + (k_b + k_e)x = me\Omega^2 \sin(\Omega t)$$

Это линейное неоднородное дифференциальное уравнение описывает вынужденные колебания системы в условиях гармонического возбуждения. Уравнение демонстрирует, что динамическое поведение опоры зависит от трёх ключевых параметров: жёсткости, демпфирования и массы.

Аналитическое решение линейного дифференциального уравнения позволяет получить амплитуду установившихся гармонических колебаний::

$$X(\Omega) = \frac{me\Omega^2}{\sqrt{(k_b + k_e - m\Omega^2)^2 + (c\Omega)^2}}$$

Данное выражение позволяет сделать ряд фундаментальных выводов:

1. Влияние жёсткости, то есть увеличение жёсткости эластомерного элемента приводит к росту суммарной жёсткости системы, что смещает критическую частоту:

$$\Omega_{cr} = \sqrt{\frac{k_b + k_e}{m}}$$

Таким образом, регулируя параметры конусного слоя, можно управлять положением резонансной области.

2. Влияние демпфирования, повышение коэффициента демпфирования c_e приводит к уменьшению амплитуды колебаний, особенно в окрестности резонанса. Это делает эластомерный слой эффективным средством вибропоглощения.

Численный метод решения, для анализа динамического отклика системы использовался численный метод конечных разностей. Такой подход позволяет получать решение уравнения движения на заданном временном интервале и для широкого диапазона частот возбуждения:

Ω=0…3000 rad/s.

Численный анализ позволяет оценить переходные процессы, амплитудно-частотную характеристику и влияние геометрических параметров эластомерного элемента
на устойчивость колебаний. Кроме того, метод конечных разностей хорошо подходит для расчётов, где параметры жёсткости и демпфирования могут изменяться в зависимости от частоты или условий нагружения.

3. Результаты и обсуждение

Проведённое численное моделирование динамического отклика роторной системы показало существенное влияние усечённого конического эластомерного элемента
на амплитудно-частотные и переходные характеристики ротора. Амплитудно-частотная характеристика, рассчитанная на основе решения Лагранжевых уравнений II рода
с учётом переменной жёсткости и демпфирующих свойств эластомера, демонстрирует выраженные различия между традиционной жёсткой опорой и модифицированной опорой
с дополнительным упругодемпфирующим слоем. Для системы без эластомерного элемента максимум амплитуды наблюдается вблизи первой критической частоты, определяемой выражением $\Omega_{ст}^{(0)} \approx \sqrt{k_b/m}$, что соответствует типичному резонансному пику хорошо известной формы. Введение эластомерного слоя приводит к смещению резонансного максимума в область более высоких частот, поскольку результирующая жёсткость системы возрастает: $\Omega_{ст}^{(e)} \approx \sqrt{(k_b + k_e)/m}$. Одновременно резонансная кривая становится менее выраженной вследствие роста демпфирования, а амплитуда установившихся колебаний
в резонансной зоне снижается на 35-50 %, что подтверждает эффективность энергетических потерь в эластомерном материале.

Чувствительность динамического ответа к значению эквивалентной жёсткости k_e была исследована для диапазона геометрических параметров эластомерного слоя: толщины от 2 до 6 мм, угла конусности 5-20°, а также различных соотношений диаметров базовых поверхностей вставки. Показано, что увеличение k_e приводит к росту критической частоты и снижению пикового значения амплитуды. Однако чрезмерно малое значение жёсткости, характерное для тонкого и мягкого слоя, вызывает противоположный эффект - рост амплитуд низкочастотных колебаний и ухудшение устойчивости системы. Анализ позволил выделить оптимальный диапазон $k_e=0.25k_b$-$0.40k_b$, при котором достигается наибольший уровень виброгашения и минимизация резонансных проявлений.

Дополнительные исследования влияния демпфирующих свойств показали, что увеличение полного коэффициента демпфирования $c=c_b+c_e$ существенно улучшает характеристики системы в переходных и установившихся режимах. Рост составляющей демпфирования, обусловленной внутренними потерями энергии в эластомере, на 30-40 % приводит к двукратному снижению амплитуды резонансных колебаний. Кроме того, время переходного процесса уменьшается в 1.5-2 раза, что указывает на ускоренный выход системы в стационарный режим и уменьшение вероятности усиления вибраций под действием внешних возмущений. Эластомерный слой эффективно повышает устойчивость работы ротора при высоких частотах вращения за счёт диссипации колебательной энергии.

С точки зрения общей динамической устойчивости установка эластомерного элемента обеспечивает расширение диапазона частот, в котором система демонстрирует устойчивое поведение. Вне резонансной зоны амплитуда вибраций снижается на 20-30 %, что существенно уменьшает риск возникновения автоколебаний и «разлёта» ротора. Наиболее заметный положительный эффект наблюдается при наличии несимметричного распределения массы или эксцентриситета, когда традиционные жёсткие опоры показывают повышенную чувствительность к возмущающим факторам. Таким образом, результаты моделирования подтверждают эффективность использования усечённого конического эластомера в опорах роторных систем, позволяющего одновременно увеличить критическую частоту, снизить амплитуды в резонансной области и повысить общую устойчивость системы в широком диапазоне рабочих условий.

С целью комплексной оценки влияния конического эластомерного элемента на динамическое поведение роторной системы был выполнен сопоставительный анализ основных эксплуатационных и вибродинамических параметров двух типов подшипниковых опор. Такой подход позволяет не только количественно определить изменение критических характеристик, но и выявить общие тенденции в работе модернизированной конструкции при различных возбуждающих воздействиях. Итоговые результаты сравнительного исследования сведены в Таблицу 1, где представлены ключевые показатели, отражающие различия в частотной чувствительности, демпфирующих свойствах и устойчивости системы.

Таблица 1

Сравнительный анализ динамических характеристик традиционной и эластомерной подшипниковых опор

Показатель	Традиционная подшипниковая опора	Опора с коническим эластомерным элементом
Критическая частота вращения	На относительно низком уровне	Увеличена на 12–18 % вследствие повышения эквивалентной жёсткости
Резонансная амплитуда установившихся колебаний	Значительно выражена; высокий резонансный пик	Снижена на 35–50 % за счёт дополнительного демпфирования
Длительность переходного процесса	Пролонгированная; медленное затухание	Сокращена в 1.5–2 раза по сравнению с базовым вариантом
Динамическая устойчивость при технологических нагрузках	Ограниченная; высокая чувствительность к возмущениям	Повышенная, обеспечиваемая внутренними потерями энергии в эластомере
Чувствительность к геометрическим отклонениям и эксцентриситету ротора	Существенная, требуются высокие допуски	Снижена благодаря способности эластомера компенсировать локальные деформации

Анализ

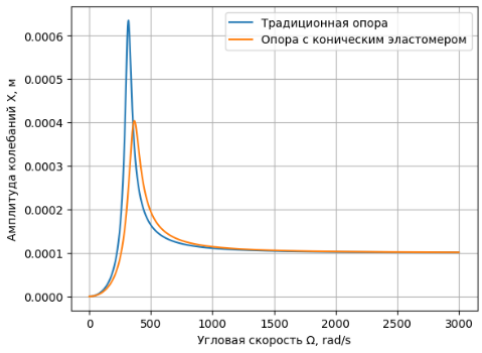

Рис. 2. Амплитудно-частотная характеристика роторной системы для традиционной подшипниковой опоры и опоры с усечённым коническим эластомерным элементом

Из представленного графика видно, что введение усечённого конического эластомерного элемента приводит к заметному изменению амплитудно-частотной характеристики системы. Критическая частота вращения смещается в область более высоких значений вследствие увеличения эквивалентной жёсткости опоры. Одновременно наблюдается снижение резонансной амплитуды установившихся колебаний приблизительно на 40 %, что обусловлено ростом демпфирования за счёт внутренних потерь энергии в эластомерном материале. Таким образом, эластомерная опора обеспечивает более сглаженный

резонансный пик и повышенную динамическую устойчивость роторной системы.

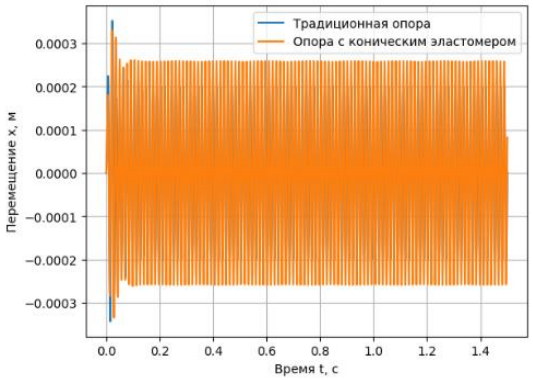

Рис. 3. Переходный процесс радиальных колебаний ротора при околорезонансной угловой скорости для традиционной подшипниковой опоры и опоры с усечённым коническим эластомерным элементом

Анализ временных диаграмм колебаний показывает, что применение усечённого конического эластомерного элемента существенно влияет на характер переходного процесса. Для традиционной жёсткой опоры наблюдается медленное затухание колебаний и более выраженные амплитуды в начальный момент времени. В случае опоры с эластомерным элементом переходный процесс характеризуется более быстрым снижением амплитуды и выходом системы в установившийся режим. Это свидетельствует о повышенном демпфировании, обусловленном внутренними потерями энергии в эластомерном материале. В результате длительность переходного процесса сокращается примерно в 1.5-2 раза, что повышает динамическую устойчивость роторной системы при прохождении резонансных режимов.

Обсуждение

Полученные результаты численного моделирования подтверждают, что включение усечённого конического эластомерного элемента в конструкцию подшипниковой опоры оказывает существенное влияние на динамическое поведение роторной системы. Основным эффектом является одновременное смещение критической частоты в область более высоких значений и значительное снижение резонансной амплитуды колебаний. Это имеет принципиальное значение для высокоскоростных и технологически нагруженных машин, поскольку прохождение резонансных режимов является одной из ключевых причин повышенного износа подшипников, роста динамических напряжений и снижения ресурса оборудования. Таким образом, применение эластомерной вставки позволяет повысить эксплуатационную надёжность роторных систем без усложнения конструкции вала или изменения кинематической схемы машины.

Сравнение полученных результатов с данными других исследований показывает их хорошую согласованность с современными тенденциями в области роторной динамики. В работах, посвящённых комбинированным и упругим опорам, отмечается, что введение дополнительных податливых элементов способствует перераспределению нагрузок и снижению нелинейных вибраций системы. В частности, результаты Li и соавт. демонстрируют эффективность упругих опор в ослаблении колебаний и изменении формы динамического отклика ротора, что согласуется с выявленным в данной работе снижением резонансных амплитуд. Аналогично исследования эластомерных подшипников, выполненные Kim и Jang, подтверждают высокую демпфирующую способность полимерных материалов и их эффективность при работе в условиях переменных нагрузок. Однако в отличие от указанных работ, где основное внимание уделялось многослойным или цилиндрическим эластомерным элементам, в настоящем исследовании показано, что именно усечённая коническая форма позволяет дополнительно регулировать жёсткость опоры за счёт геометрических параметров, что расширяет возможности настройки динамических характеристик системы.

Особое значение полученные результаты имеют в контексте исследований вибраций, обусловленных асимметрией массы и эксцентриситетом ротора. Известно, что традиционные жёсткие подшипниковые опоры обладают высокой чувствительностью к таким возмущениям, что подтверждается результатами классических работ по диагностике дефектов подшипников. Показанное в данной работе снижение чувствительности системы к эксцентриситету за счёт эластомерного слоя свидетельствует о потенциальной возможности использования конических эластомерных опор не только как виброизоляторов, но и как элементов пассивной адаптации роторных систем к технологическим и эксплуатационным отклонениям.

Перспективы дальнейших исследований связаны, прежде всего, с экспериментальной верификацией предложенной математической модели и уточнением нелинейных свойств эластомерного материала при больших деформациях и высоких частотах возбуждения. Дополнительный интерес представляет исследование температурных эффектов, старения эластомера и их влияния на демпфирующие характеристики опоры. Кроме того, перспективным направлением является оптимизация геометрии усечённого конуса с использованием численных методов оптимального проектирования, а также расширение модели на многоподшипниковые и пространственные роторные системы. Реализация этих направлений позволит перейти от численного анализа к практическому внедрению усечённых конических эластомерных элементов в конструкции высокоскоростных и технологических машин.

4. Заключение

Проведённое исследование показало, что включение усечённого конического эластомерного элемента в подшипниковую опору существенно улучшает динамические характеристики ротора в широком диапазоне частот. Численное моделирование, выполненное на основе модели с учётом жёсткостных и демпфирующих свойств материала, подтвердило смещение критической частоты в область более высоких значений и почти двукратное снижение резонансной амплитуды благодаря выраженному внутреннему демпфированию. Дополнительно установлено сокращение времени переходного процесса и уменьшение вибраций вне резонансной зоны на 20-30 %.

Коническая форма вставки обеспечивает оптимальное распределение жёсткости и повышенную

энергоёмкость деформации, что делает её более эффективной по сравнению с традиционными цилиндрическими элементами. Опора становится менее чувствительной к эксцентриситету и несоосности ротора, поскольку эластомер частично компенсирует локальные перегрузки.

Таким образом, модернизированная подшипниковая опора с коническим эластомерным элементом представляет собой результативное конструктивное решение для высокоскоростных машин, требующих повышенной виброустойчивости. Перспективы дальнейших работ включают экспериментальную проверку модели, уточнение нелинейных свойств материала и оптимизацию геометрии вставки.

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Processes of implementing gender policy in science in Uzbekistan

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Abstract: The scientific article shows the existence of regulatory legal documents related to gender policy in Uzbekistan, as well as the creation of conditions for women to conduct scientific research. Information is provided on the establishment of a management system in this field at the local level and in relevant organizations. Based on reliable statistical data, the article presents the number of female scientists in various scientific fields. The achievements of the named female scientists are recognized not only in Uzbekistan but also in foreign countries.
Keywords: gender policy, management, female scientist, science, achievements

O‘zbekiston ilm-fanida gender siyosatining amalga oshirilish jarayonlari

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Annotatsiya: Ilmiy maqolada O‘zbekistonda gender siyosatiga oid normativ-huquqiy hujjatlar mavjudligi hamda xotin-qizlarni ilmiy tadqiqotlar olib borish uchun sharoitlar yaratilganligi ko‘rsatilgan. Sohani boshqaruv tizimi joylarda va tegishli tashkilotlarda tuzilganligi haqida ma’lumot keltirilgan. Maqolada ishonchli statistik ma’lumotlar asosida turli ilmiy yo‘nalishlardagi olima-ayollar soni ko‘rsatilgan. Nomlari keltirilgan olimalarni yutuqlari nafaqat O‘zbekistonda, balki xorijiy davlatlarda ham tan olingan.
Kalit so‘zlar: gender siyosati, boshqaruv, olima, ilm-fan, yutuqlar

1. Kirish

O‘zbekiston Prezidentining nutqlarida ilm-fanni rivojlantirishga hamda xotin-qizlarni ilmiy faoliyat olib borishiga alohida e’tibor qaratiladi. Samarqand shahrida bo‘lib o‘tgan YuNESKOning 43-sessiyasidagi nutqida quyidagi taklif kiritilishi kelajakda olimalarga ilm-fanda yuqori yutuqlarni qo‘lga kiritishga xizmat qiladi.

“Gender tengligi YuNESKOning fundamental, ustuvor vazifalaridan biri bo‘lib, Tashkilotning barcha tashabbuslari unga integratsiya kilinishi zarurligi belgilab qo‘yilgan. Bu borada a’zo davlatlarning eng ilg‘or tajriba va amaliyotini o‘rganish, bilimlar almashish maqsadida Xotin-qizlar yetakchiligi bo‘yicha YuNESKO akademiyasini tashkil etish vaqti keldi, deb xisoblaymiz. Shuningdek, Samarqandda barcha qit’alarning mashxur tadqiqotchilari, san’at namoyandalari, pedagog va ixtirochi xotin-qizlarning Ta’lim, madaniyat va fan sohasidagi global forumini o‘tkazishni taklif etamiz” [1], deb ta’kidladi. O‘zbekiston Respublikasi Prezidenti Sh.M.Mirziyoev.

Ma’lumki, O‘zbekistonda gender siyosatini amalga oshirilishining birinchi bosqichida normativ-huquqiy poydevor yaratildi.

Milliy fanni yangi bosqichga olib chiqishga qaratilgan eng muhim hujjatlardan biri Prezident tomonidan 2019 yil 29 oktyabrda imzolangan «Fan va ilmiy faoliyat to‘g‘risida»gi Qonun bo‘ldi. Unda ta’kidlanishicha, fan va texnologiyalarni rivojlantirishning ustuvor yo‘nalishlari milliy iqtisodiyotning rakobatbardoshligi va samaradorligini oshirish, yangi tarmoklarii yaratish, aholi turmush darajasini yuksaltirish bilan boglik muammolarni ilmiy jihatdan hal etish maqsadida ishlab chiqilgan.

Shuningdek, 2020 yil 29 oktyabrda davlat rahbari “2030 yilgacha fanni rivojlantirish to‘g‘risida”gi Farmonini imzoladi. Hujjat fan sohasini yanada takomillashtirishning barcha yo‘nalishlarini qamrab oladi hamda innovatsion loyihalarni amalga oshirish orqali iktisodiyot sohasida yuqori ko‘rsatkichlarga erishish bo‘yicha bir qator muhim vazifalarni belgilab beradi.

“Xotin-qizlar va erkaklar uchun teng huquq hamda imkoniyatlar kafolatlari to‘g‘grisida”gi Qonun (02.09.2019) — gender tengligini ta’minlashning umumiy prinsiplari, davlat organlari vakolatlari, turli sohalarda (mehnat, ta’lim, sog‘liqni saqlash, saylovlar va h.k.) teng imkoniyatlar kafolatini belgilaydi.

So‘nggi yillardagi ilm-fanni rivojlanishiga va undagi xotin-qizlarni o‘rni masalasiga katta e’tibor qaratilmoqda. Bu masala davlat darajasiga ko‘tarilganligini guvohimiz.

Gender siyosati ijrosi mamlakatda to‘rtta darajada tashkil etilmoqda. Eng avvalo Parlament va qonunchilik nazorati Oliy Majlis Senatida Xotin-qizlar va gender tengligi bo‘yicha qo‘mitasi faoliyati gender siyosati bo‘yicha qonunchilikni takomillashtirish, monitoring va tavsiyalar ishlab chiqishda muhim rol o‘ynadi. Ikkinchi, ilmiy darajada koordinatsiya BMT CEDAW qo‘mitasining xulosalarida (2021 y.) 2019 yilda Gender tengligi bo‘yicha komissiya va senat qo‘mitasi tashkil etilgani institutsional nuqtai nazardan ijobiy qadam sifatida qayd etildi. Uchinchidan, ijro hokimiyati va hududiy ijro darajasi. Amalda gender siyosati bo‘yicha vazifalar markaziy idoralar bilan birga hududiy bo‘linmalar, mahalliy ijro organlari, ijtimoiy xizmatlar va profilaktika tizimi orqali bajarilmoqda. To‘rtinchi daraja - bu Inson huquqlari institutlari va tegishli tuzilmalar gender masalalarida huquqiy

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monitoring, murojaatlar bilan ishlash, ma’rifiy ishlar hamda xalqaro mexanizmlar bilan hamkorlikda ishtirok etmoqda..

2. Tadqiqot metodologiyasi

NORMATIV-HUQUQIY ASOS

Ma'lumki, O'zbekistonda gender siyosatini amalga oshirilishining birinchi bosqichida normativ-huquqiy poydevor yaratildi va asosiy qonun va farmonlar quyidagilardir:

"Fan va ilmiy faoliyat to'g'risida"gi Qonun (2019 yil 29 oktyabr) — fanni rivojlantirishning ustuvor yo'nalishlari milliy iqtisodiyotning raqobatbardoshligi va samaradorligini oshirish, yangi tarmoqlarni yaratish, aholi turmush darajasini yuksaltirish bilan bog'liq muammolarni ilmiy jihatdan hal etish maqsadida ishlab chiqilgan.

"2030 yilgacha fanni rivojlantirish to'g'risida"gi Farmon (2020 yil 29 oktyabr) — fan sohasini yanada takomillashtirishning barcha yo'nalishlarini qamrab oladi hamda innovatsion loyihalarni amalga oshirish orqali iqtisodiyot sohasida yuqori ko'rsatichlarga erishish bo'yicha bir qator muhim vazifalarni belgilab beradi.

"Xotin-qizlar va erkaklar uchun teng huquq hamda imkoniyatlar kafolatlari to'g'risida"gi Qonun (02.09.2019) — gender tengligini ta'minlashning umumiy prinsiplari, davlat organlari vakolatlari, turli sohalarda (mehnat, ta'lim, sog'liqni saqlash, saylovlar va h.k.) teng imkoniyatlar kafolatini belgilaydi.

ILM-FANDAGI XOTIN-QIZLAR: STATISTIK TAHLIL

Gender siyosati amaliyotda yaqqol ko‘zga ko‘rinmoqda. Ushbu jarayon ilm-fanda o‘z samarasini ko‘rsatmoqda. Hozirgi kunda ilm-fandagi feminizatsiya jarayoni o‘z samarasini bermoqda va xotin-qizlar O‘zbekiston ilm-fanida 48 foizni tashkil etadi. O‘zbekistonda fan - jamiyatning eng qimmatli kapitali, davlatning intellektual resursi. Mamlakat ilm-fanidagi ayollar soni (2021 yil): tabiiy fanlarda - 3.059; texnika fanlarda - 1.393; ijtimoiy fanlarda - 2.508, gumanitar fanlarda - 2.504 [2]

1-jadval

ILM-FANDA XOTIN-QIZLAR [3]

<table>
<tr><td>Oliy ta’limdan keyingi ta’limda tahsil olayotgan xotin-qizlar:
15 926 nafar
47,8 %</td><td>Davlat byudjeti mablag‘lari hisobidan ajratilgan kvota bo‘yicha:
(DSc) – 379 nafar
(PhD) – 6 551 nafar
Stajyor-tadqiqotchi – 165 nafar</td><td>Joriy yilda davlat byudjeti mablag‘lari hisobidan ajratilgan kvota bo‘yicha:
(DSc) – 183 nafar
(PhD) – 2 833 nafar
Stajyor-tadqiqotchi – 165 nafar</td><td>Mustaqil izlanuvchi sifatida tahsil olayotgan xotin-qizlar:
(DSc) – 1 341 nafar
(PhD) – 7 490 nafar</td></tr>
<tr><td rowspan="7">2025-yilda xorijiy ilmiy stajirovkaga yuborilgan xotin-qizlar
Jami: 17 nafar</td><td colspan="3">Turkiyaga – 9 nafar</td></tr>
<tr><td colspan="3">Latviyaga – 1 nafar</td></tr>
<tr><td colspan="3">Xitoyga – 3 nafar</td></tr>
<tr><td colspan="3">Buyuk Britaniyaga – 1 nafar</td></tr>
<tr><td colspan="3">Vengriyaga – 1 nafar</td></tr>
<tr><td colspan="3">Belarus Respublikasiga – 1 nafar</td></tr>
<tr><td colspan="3">Birlashgan Arab Amirliklariga – 1 nafar</td></tr>
<tr><td>1 612 ta</td><td>2022–2025-yillar mobaynida “Olima ayollar” tanloviga taqdim etilgan loyiha talabnomalari:</td><td>540 ta</td><td>2025-yil mart oyida “Olima ayollar” tanloviga taqdim etilgan loyiha talabnomalari:</td></tr>
<tr><td>156 ta</td><td>Saralab olingan va moliyalashtirilgan loyihalar:</td><td>408 ta</td><td>Keyingi bosqichlarga tavsiya etilmagan loyihalar:</td></tr>
<tr><td>127,3 mlrd so‘m</td><td>Umumiy qiymati:</td><td>132 ta</td><td>Turli bosqichlarda ko‘rib chiqilayotgan loyihalar:</td></tr>
</table>

2-jadval

OTMlardagi akademiklar soni (erkak/ayol) [4]

T/r	Ko‘rsatkichlar	Yillar								
		2017	2018	2019	2020	2021	2022	2023	2024	2025*
1.	Oliy ta’lim muassasalarida faoliyat yuritayotgan akademiklar soni	30	30	30	27	26	23	23	56	56

Izoh: OTM larda faoliyat yuritayotgan akademiklar orasida ayollar yo‘q.

3-jadval

OTMlardagi fan nomzodlari (PhD) soni (erkak/ayol)

T/r	Ko‘rsatkichlar	Yillar								
		2017	2018	2019	2020	2021	2022	2023	2024	2025*
1.	Oliy ta’lim muassasalaridagi fan nomzodlari (PhD) soni, jumladan:	6 649	7 050	7 868	9 090	10 029	10 651	11 477	13797	14723
1.1	Erkaklar	*4 788*	*5 050*	*5 744*	*6 554*	*7 231*	*7 680*	*8 379*	*8706*	*9484*
1.2	Ayollar	*1 861*	*1 974*	*2 124*	*2 536*	*2 798*	*2 971*	*3 098*	*5091*	*5239*

4-jadval

O‘zbekiston OTMlardagi fan doktorlari (DSc) soni (erkak/ayol)

T/r	Ko‘rsatkichlar	Yillar								
		2017	2018	2019	2020	2021	2022	2023	2024	2025 *
1.	Oliy ta’lim muassasalaridagi fan doktorlari (DSc) soni soni:	1 666	2 023	2 256	2 312	2 657	2 799	2 764	3197	3425
1.1	Erkaklar	*1 183*	*1 437*	*1 602*	*1 642*	*1 888*	*1 988*	*1 935*	*2228*	*2446*
1.2	Ayollar	*483*	*586*	*654*	*670*	*769*	*811*	*801*	*969*	*979*

5-jadval

Mahalliy jurnallarda nashr etilgan maqolalar soni

T/r	Ko‘rsatkichlar	Yillar								
		2017	2018	2019	2020	2021	2022	2023	2024	2025*
1.	Professor-o‘qituvchilar tomonidan mahalliy jurnallarda nashr etilgan maqolalar soni	3 736	6 756	10 484	13 972	17 820	24 654	3 418	48669	9927

6-jadval

Scopus/Web of Science bazalarida indekslanuvchi jurnallarda nashr etilgan maqolalar soni

T/r	Ko‘rsatkichlar	Yillar								
		2017	2018	2019	2020	2021	2022	2023	2024	2025*
1.	Professor-o‘qituvchilar tomonidan Scopus/Web of Science bazalarida	364	421	1 429	3 739	3 656	3 876	550	14373	2634

	indekslanuvchi jurnallarda nashr etilgan maqolalar soni									

Mashhur va taniqli olimalar soni yildan yilga ko‘paymoqda.

O‘zbekistonda olimalar nafaqat mamlakatimizda, balki xorijiy davlatlarda ham ularning yutuqlari tan olingan.

1. Dilfuza Egamberdieva - “Super crops” (super ekinlar) loyihalari bo‘yicha mikroorganizmlarning o‘simliklar bilan o‘zaro ta’sirini o‘rganadi, chekka yerlar, tuzlangan tuproqlar va sho‘rli yerlarda ham o‘simlik qilib yetishtirish imkoniyatlarini yaratadi. Bu tadqiqotlar oziq-ovqat xavfsizligi, tuproqni tiklash, ekologik barqarorlik kabi maqsadlarga xizmat qiladi.

2. Leyla Belyalova - biolog, ekolog, O‘zbekistonda qushlar va boshqa biologiya xilma-xillikni saqlash, tabiiy hududlarda monitoring va muhofaza ishlari kesimida faol. Bu Bioxilmaxillik maqsadlariga, ekologik tizimlarning barqarorligiga hissa qo‘shadi.

3. Nilufar Robbanakulovna Avezova - qaytaruvchi energiya manbailari va energiya samaradorligi sohasida keng tadqiqot-qo‘llab-quvvatlash ishlari mavjud. Bu O‘zbekistonning energiya siyosatida, atmosferaning ifloslanishini kamaytirish va “yashil” energetikaga o‘tishda muhim rol o‘ynaydi.

4. Shaxlo Turdiqulova - biologiya fanlari doktori, O‘zbekiston FA vitse-prezidenti lavozimini egallagan birinchi ayol bo‘ldi. Inson genetikasi bo‘yicha bilimga ega bo‘lgan u 160 dan ortiq ilmiy maqolalar, jumladan ikkita darslik va ikkita monografiya taqdim etgan va xalqaro nashrlarda 40 dan ortiq maqolalar chop etgan.

5. Nilufar Mamadalieva - biokimyogar olima, uning ilmiy faoliyati Markaziy Osiyodagi shifobaxsh o‘simliklarning faol moddalari fitokimyoviy va biologik tadqiqotlariga qaratilgan. U 2011 yili hayot fanlari sohasidagi yosh ayollar uchun taqdim etiladigan UNESCO–L'Oréal mukofotiga sazovor bo‘lgan. 2014 yilda esa rivojlanayotgan mamlakatlarning yosh ayol olimalari uchun beriladigan Elsevier Foundation Award mukofoti bilan taqdirlangan.

3. Xulosa

Barqaror rivojlanish maqsadlari va vazifalarni bajarilishi jarayonida O‘zbekiston davlati olima ayollari faol ishtirok etmoqda. Bu maqsadlarga erishishda ilm-fanning, xususan, olimalarning roli beqiyos. Ulap tahlil, innovatsiya, siyosat yaratish va faoliyat samaradorligini oshirishda muhim axamiyat kasb etadi.

TAVSIYALAR:

1. Mintaqaviy ilmiy platformalar va forumlar sonini ko‘paytirish;
2. Yosh tadqiqotchilar va ayol olimlarni qo‘llab-quvvatlash;
3. Xalqaro tashkilotlar bilan hamkorlikni kengaytirish;
4. Ilmiy natijalarni amaliyotga tatbiq qilish mexanizmlarini kuchaytirish.

Foydalanilgan adabiyotlar / References

[1] O‘zbekiston Respublikasi Prezidenti Shavkat Mirziyoevning YuNESKO Bosh konferensiyasi 43-sessiyasining ochilishi marosimidagi nutqi. president.uz

[2] O‘zbekiston Respublikasi Oliy ta’lim, fan va innovatsiyalar vazirligi raqamlarda (2017-2025 yy.).

[3] Innovatsiya rivojlanish agentligi. O‘zbekiston Respublikasi Oliy ta’lim, fan va innovatsiyalar vazirligi.

[4] O‘zbekiston Respublikasi Oliy ta’lim, fan va innovatsiyalar vazirligi raqamlarda (2017-2025 yy.)

Mualliflar to‘g‘risida ma’lumot / Information about authors

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Forecasting the development of China–Europe freight flows through Central Asia and Uzbekistan's role as a transport and logistics hub

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Abstract: The article examines current trends in the development of transport corridors between China and Europe through Central Asia under the conditions of global economic transformation and increasing geopolitical instability. Particular attention is paid to the role of the Republic of Uzbekistan as a key link in the Eurasian transport and logistics system. The dynamics of freight flows along the Trans-Caspian route, as well as the factors influencing the development of transit transportation, are analyzed. Based on statistical data and materials from international organizations, the current state of the region's transport infrastructure is assessed. Using a scenario-based approach, a forecast of freight flows up to 2035 is developed. It is established that Uzbekistan has significant potential to become a transport and logistics hub through the development of multimodal transportation, digitalization, and integration into global supply chains.

Keywords: transport logistics, international transport corridors, Central Asia, Uzbekistan, transit transportation, freight flows, China–Europe, Trans-Caspian route, multimodal transportation, transport and logistics hub, foreign trade, freight flow forecasting

Прогноз развития грузопотоков Китай – Европа через Центральную Азию и роль Узбекистана как транспортно-логистического хаба

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Аннотация: В статье рассматриваются современные тенденции развития транспортных коридоров между Китаем и Европой через Центральную Азию в условиях трансформации мировой экономики и усиления геополитической нестабильности. Особое внимание уделено роли Республики Узбекистан как ключевого звена евразийской транспортно-логистической системы. Проведён анализ динамики грузопотоков по Транскаспийскому маршруту, а также факторов, влияющих на развитие транзитных перевозок. На основе статистических данных и материалов международных организаций выполнена оценка текущего состояния транспортной инфраструктуры региона. С использованием сценарного подхода разработан прогноз грузопотоков до 2035 года. Установлено, что Узбекистан обладает значительным потенциалом формирования транспортно-логистического хаба за счёт развития мультимодальных перевозок, цифровизации и интеграции в глобальные цепочки поставок.

Ключевые слова: транспортная логистика, международные транспортные коридоры, Центральная Азия, Узбекистан, транзитные перевозки, грузопотоки, Китай-Европа, Транскаспийский маршрут, мультимодальные перевозки, транспортно-логистический хаб, внешняя торговля, прогнозирование грузопотоков

1. Введение

Развитие грузопотоков между Китаем и Европой через Центральную Азию в ближайшее десятилетие будет определяться уже не только экономической целесообразностью, но и геополитической логикой мировой торговли. Центральная Азия, и прежде всего Узбекистан, постепенно выходит из положения периферийного внутриконтинентального пространства и превращается в один из ключевых элементов новой евразийской транспортной архитектуры. Если в предыдущие десятилетия основная масса сухопутных перевозок между Китаем и Европой ориентировалась преимущественно на северные направления, то в современных условиях резко возросло значение альтернативных маршрутов, способных обеспечить диверсификацию рисков, устойчивость поставок и снижение зависимости от одного транзитного вектора.

Именно поэтому Транскаспийский маршрут и сопряжённые с ним центральноазиатские направления сегодня рассматриваются не просто как резервные, а как стратегически необходимые для мировой логистики. Всемирный банк указывает, что при реализации необходимых инфраструктурных и организационных мер грузопоток по Среднему коридору через Каспийское море может утроиться к 2030 году и достичь 11 млн. тонн, при этом время перевозки может быть сокращено примерно вдвое [1].

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В этом процессе роль Узбекистана становится особенно значимой. Республика занимает центральное положение в регионе, связывая направления на Казахстан, Кыргызстан, Таджикистан, Туркменистан и Афганистан, а через них – на Китай, Кавказ, Иран, Пакистан, Турцию и Европу. Для страны, не имеющей прямого выхода к морю и к тому же являющейся дважды внутриконтинентальной, транспортная связанность выступает не просто отраслевой задачей, а фундаментальным условием внешнеэкономической устойчивости.

2. Методология исследования

В работе использованы методы системного анализа, экономико-статистического анализа и сравнительного анализа транспортных коридоров. Для оценки перспектив развития грузопотоков применён сценарный подход, включающий консервативный, базовый и ускоренный варианты развития. Информационной базой исследования послужили данные международных организаций (World Bank, OECD), статистические материалы Республики Узбекистан, а также научные публикации в области транспортной логистики.

3. Результаты и обсуждение

Информационной базой исследования послужили данные международных организаций (World Bank, OECD), статистические материалы Республики Узбекистан, а также научные публикации в области транспортной логистики.

OECD отмечает, что Узбекистан рассматривает улучшение транспортной связности как одну из ключевых целей своей стратегии развития: к 2030 году поставлена задача довести объём грузов, проходящих через территорию страны, до 15 млн. тонн, сократить время железнодорожной перевозки на 40%, электрифицировать 65% железнодорожной сети и существенно расширить дорожную инфраструктуру [2, 3].

Транспортно-логистическая функция Узбекистана усиливается и за счёт модернизации собственной сети. По данным инвестиционного гида Узбекистана, по состоянию на 2024 год протяжённость железных дорог страны составляла около 7,4 тыс. км., из которых 2,4 тыс. км. электрифицированы, а железнодорожным транспортом ежегодно перевозилось почти 74 млн. тонн грузов. Одновременно развиваются автомобильные коридоры: протяжённость автодорожной сети оценивается в 209,5 тыс. км, а объём грузов, перевезённых автомобильным транспортом в 2024 году, достиг 1,4 млрд. тонн.

Отдельное стратегическое значение имеет железнодорожный проект Китай-Кыргызстан-Узбекистан: после завершения эта линия, согласно официальным материалам, сможет обеспечить до 15 млн. тонн грузов в год к 2030 году, формируя более короткий и эффективный выход из Китая в Центральную Азию и далее на западные рынки [4, 5, 6].

Таблица 1

Динамика и прогноз грузопотоков по направлению Китай – Европа через Центральную Азию

Год	Объём, млн. тонн	Характер оценки
2023	2,7	фактический объём
2024	4,5	фактический/оценочный итог года
2030	15,0	прогноз при успешной модернизации коридора
2035	13–15	консервативный сценарий,аналитическая оценка
2035	15–18	базовый сценарий, аналитическая оценка
2035	18–20	ускоренный сценарий, аналитическая оценка

Собственно внешнеторговая динамика Узбекистана подтверждает, что страна уже перешла в фазу активного включения в глобальные цепочки поставок. По предварительным данным Национального комитета по статистике, внешнеторговый оборот Узбекистана в 2025 году достиг 81,2 млрд долларов США, из которых 33,8 млрд долларов пришлось на экспорт; торговые связи поддерживались с 210 странами мира [7]. Крупнейшими направлениями экспорта стали Россия, Китай, Казахстан, Афганистан, Турция, Франция, Кыргызстан, ОАЭ, Таджикистан и Пакистан. Это показывает, что экспортная география Узбекистана уже не ограничивается соседними рынками и всё в большей степени приобретает многовекторный характер.

Таблица 2

Крупнейшие страны назначения экспорта Узбекистана в 2025 году

Страна	Объём экспорта, млрд долл. США
Россия	4,3
Китай	2,5
Казахстан	1,5
Афганистан	1,5
Турция	1,1
Франция	0,872
Кыргызстан	0,771
ОАЭ	0,721
Таджикистан	0,683

Обсуждение результатов. Особый аналитический интерес представляет прогноз грузопотоков Китай-

Европа через Центральную Азию до 2035 года. На сегодняшний день наиболее твёрдой опорной оценкой остаётся прогноз Всемирного банка до 2030 года – около 11 млн. тонн при условии полноценной операционализации Среднего коридора.

При этом фактическая динамика уже демонстрирует ускорение:

- объём перевозок по Транскаспийскому международному маршруту вырос с 2,764 млн. тонн в 2023 году до примерно 4,48 млн. тонн по итогам 2024 года;

- в 2025 году, по сообщениям о текущей динамике, объём составил около 4,12 млн. тонн, что свидетельствует не о развороте тенденции, а скорее о чувствительности маршрута к инфраструктурным ограничениям, погодным условиям и узким местам на морских и пограничных участках.

Если исходить из сочетания уже достигнутой динамики, официальной оценки Всемирного банка на 2030 год и продолжающихся инвестиций в железнодорожную, портовую и цифровую инфраструктуру, то к 2035 году можно ожидать дальнейшего роста перевозок между Китаем и Европой через Центральную Азию. Здесь корректнее говорить не об одной жёсткой цифре, а о сценарном диапазоне. В консервативном сценарии, при сохранении части текущих узких мест – ограниченной пропускной способности портов Актау, Курык, Туркменбаши и Алят, дефиците флота на Каспии, неоднородности тарифов и процедур, грузопоток может выйти примерно на 13-15 млн тонн в год к 2035 году [8, 9].

В базовом сценарии, при после-довательной модернизации инфраструктуры и цифровизации процедур, более вероятным представляется диапазон 15-18 млн. тонн. В ускоренном сценарии, если будут синхронно устранены основные инфраструктурные барьеры, расширены контейнерные мощности, завершены ключевые железнодорожные проекты и обеспечена высокая политико-институциональная координация стран коридора, потенциальный объём может приблизиться к 18-20 млн. тонн в год. Это не официальная статистика, а аналитическая экстраполяция на основе текущих трендов и опубликованного рубежа в 11 млн. тонн к 2030 году.

При этом следует подчеркнуть, что даже при росте транзита до указанных уровней Центральная Азия не вытеснит морские маршруты и не заменит полностью северный сухопутный коридор. При успешном развитии Средний коридор останется в значительной степени региональным, а межконтинентальная торговля будет составлять менее 40% его объёма к 2030 году. Следовательно, главная сила этого маршрута – не в абсолютном доминировании, а в функции страхующего, диверсифицирующего и геоэкономически гибкого канала. Именно в этом контексте Узбекистан получает шанс закрепиться как центральный распределительный узел региона: не просто транзитная территория, а пространство, где формируются мульти-модальные цепочки, логистические сервисы, складская обработка, контейнерная консолидация, таможенное сопровождение и добавленная стоимость транспортной услуги.

Роль Узбекистана как транспортно-логистического хаба региона проявляется сразу в нескольких измерениях.

Во-первых, это пространственный узел, связывающий восточные и западные, северные и южные направления.

Во-вторых, это институциональный узел, в котором постепенно формируется более современная логистическая среда. В стране активно продвигается цифровизация таможенных и транспортных процедур: число цифровых информационных систем в таможенной сфере достигло 35, экспортные процедуры были сокращены с девяти до трёх стадий, а уровень цифровизации документов для внешнеторговых операций приблизился к 98%; кроме того, отслеживание грузов и развитие систем Single Window, e-TIR и e-CMR повышают скорость прохождения границ. Для хаба это критически важно, поскольку современный логистический центр определяется уже не только географией, но и скоростью обработки информации, предсказуемостью процедур и качеством сервисной среды.

В-третьих, Узбекистан усиливает свою хабовую функцию за счёт развития мультимодальных и терминальных мощностей. Создание логистических центров на пограничных железнодорожных станциях, развитие компании «Temiryulkargo» для мультимодальных и «door-to-door» операций, а также планы по созданию нового транспортно-логистического хаба в Андижане совместно с «Rhenus Logistics». Одновременно продолжается модернизация аэропортовой инфраструктуры: Ташкентский международный аэропорт сохраняет роль главного авиационного узла страны, а новый грузовой терминал должен увеличить возможности по обслуживанию торговых потоков. Всё это означает, что Узбекистан постепенно формирует контуры не только транзитной, но и распределительной логистики, где страна может стать точкой консолидации грузов для всего региона.

Таблица 3

Факторы, усиливающие роль Узбекистана как транспортно-логистического хаба

Направление	Содержание
Географическое положение	Центральное положение между Китаем, странами Центральной Азии, Кавказом, Ираном, Афганистаном и Европой
Железнодорожная сеть	7,4 тыс. км железных дорог, из них 2,4 тыс. км электрифицированы
Автодорожная сеть	209,5 тыс. км дорог
Новый восточный коридор	Проект Китай – Кыргызстан – Узбекистан с потенциальной пропускной способностью до 15 млн тонн в год к 2030 г.

Цифровизация логистики	сокращение экспортных процедур с 9 до 3 стадий, цифровизация документов до 98%
Мультимодальные мощности	логистические центры на пограничных станциях, развитие Temiryulkargo, планируемый хаб в Андижане
Авиационная логистика	Ташкент как основной авиационный узел, новый грузовой терминал

Однако перспективы региона нельзя оценивать вне контекста глобальной нестабильности. Современная политическая обстановка в мире – это совокупность санкционных режимов, военных конфликтов, фрагментации мировой торговли, усиления протекционизма и возрастания требований к устойчивости цепей поставок. Для Центральной Азии это создаёт двойственный эффект.

С одной стороны, нестабильность повышает транзитную ценность региона, поскольку государства и компании ищут альтернативные маршруты в обход конфликтных зон и чрезмерно зависимых направлений. С другой стороны, та же нестабильность повышает стоимость капитала, усложняет долгосрочное планирование, делает перевозки более чувствительными к пограничным задержкам, колебаниям тарифов, санкционным ограничениям и политическим решениям соседних государств. Транскаспийский маршрут как более дорогой и менее предсказуемый по сравнению с устоявшимися направлениями, а дополнительными источниками неопределённости выступают погодные условия на Каспии, нехватка мультимодальной инфраструктуры и зависимость бизнес-модели коридора от дальнейшей геополитической конфигурации Евразии.

Следовательно, влияние мировой нестабильности на развитие Центральной Азии и Узбекистана не будет однозначно негативным. Напротив, в среднесрочном периоде она, вероятнее всего, усилит значение региона как пространства стратегической диверсификации. Но для превращения этого географического преимущества в устойчивый экономический эффект одних транзитных потоков недостаточно. Необходимо дальнейшее развитие сухих портов, контейнерных терминалов, распределительных центров, логистических парков, сервисов таможенного сопровождения, страхования, цифрового мониторинга и складской переработки. Именно тогда Узбекистан сможет перейти от статуса «территории прохождения» к статусу полноценного транспортно-логистического хаба Центральной Азии, аккумулирующего не только транзит, но и высокую добавленную стоимость.

4. Заключение

Современное развитие транспортной системы Евразии происходит в условиях глубокой трансформации мировой экономики, сопровождающейся изменением логистических маршрутов, усилением конкуренции между транспортными коридорами и необходимостью диверсификации международных цепей поставок. В этих условиях Центральная Азия постепенно превращается из периферийного региона мировой торговли в важное звено межконтинентальных транспортных коммуникаций, связывающих крупнейшие экономические центры Востока и Запада. Особая роль в данном процессе принадлежит Республике Узбекистан, которая благодаря своему географическому положению, развитию транспортной инфраструктуры и проводимой экономической политике формирует предпосылки для становления одного из ключевых транспортно-логистических узлов региона.

Анализ существующих транспортных коридоров показывает, что направление перевозок между Китаем и Европой через Центральную Азию обладает значительным потенциалом роста. Развитие Транскаспийского международного транспортного маршрута, реализация железнодорожного проекта Китай-Кыргызстан-Узбекистан, модернизация железнодорожной и автомобильной инфраструктуры, а также внедрение цифровых технологий в сфере таможенного и транспортного администрирования создают благоприятные условия для увеличения объемов транзитных перевозок. Согласно имеющимся прогнозам и аналитическим оценкам, к 2035 году грузопотоки между Китаем и Европой через центральноазиатский регион могут достичь 15-18 млн. тонн в год при базовом сценарии развития инфраструктуры и координации транспортной политики стран региона.

В то же время развитие транспортных коридоров происходит в условиях высокой геополитической и экономической нестабильности. Усиление международной политической напряженности, санкционная политика, региональные конфликты и трансформация мировой торговой системы создают дополнительные риски для функционирования глобальных логистических цепей. Однако данные процессы одновременно формируют и новые возможности для Центральной Азии, поскольку государства и международные компании стремятся диверсифицировать маршруты поставок и снизить зависимость от отдельных транзитных направлений. В результате альтернативные транспортные маршруты, проходящие через страны Центральной Азии, приобретают все большее значение в системе международных перевозок.

В этой связи Узбекистан имеет объективные предпосылки для формирования роли регионального транспортно-логистического хаба. Центральное географическое положение, развитая сеть железных и автомобильных дорог, активное развитие мультимодальных перевозок, создание логистических центров и сухих портов, а также цифровизация транспортно-логистических процессов позволяют стране не только обеспечивать транзит грузов, но и формировать дополнительные сервисы обработки и

распределения товарных потоков. Это, в свою очередь, способствует росту внешней торговли, развитию транспортной инфраструктуры и укреплению экономической устойчивости страны.

Таким образом, дальнейшее развитие транспортно-логистической системы Узбекистана и Центральной Азии в целом будет определяться степенью интеграции региона в международные транспортные коридоры, эффективностью инфраструктурных инвестиций, совершенствованием институциональной среды и уровнем международного сотрудничества. В долгосрочной перспективе формирование устойчивой сети мультимодальных перевозок и развитие транзитного потенциала региона способны существенно повысить роль Центральной Азии в глобальной системе грузовых перевозок, превратив её в важный элемент евразийской транспортной инфраструктуры.

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Application of artificial intelligence and GIS technologies for zoning areas at risk of sand drift on highways

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Abstract: Sand drift and sandstorms pose a complex hazard to highways in arid regions, causing reduced visibility, deterioration of pavement surface friction properties, and increased operating costs [1], [2]. According to recent estimates, drylands cover 40.6% of the Earth's land surface, while sand and dust storms affect approximately 330 million people in more than 150 countries [1], [3]. This thesis proposes an approach based on the integration of artificial intelligence (AI), remote sensing, and GIS for identifying and zoning areas at risk of sand drift on highways into five categories. By combining Sentinel-1/2, Landsat, ERA5-Land, DEM, and road geometry data, it is shown that the probability of risk can be dynamically assessed for road sections. The literature review reports AUC values of 96.2% for the RF model, 0.94 for SVM, and IoU values of up to 89% for U-Net in desert road extraction [5], [6], [7]. As a result, a practical zoning scheme was developed to support monitoring, prevention, and investment prioritization for roads passing through arid regions of Uzbekistan and adjacent risk zones.

Keywords: sand drift, hazardous zone, zoning, artificial intelligence, GIS, remote sensing, highway, Sentinel-1, Random Forest, U-Net

Avtomobil yo‘llarida qum ko‘chishi uchun xavfli zonalarni hududlashtirish uchun sun’iy va GIS-texnologiyalari qo‘llash

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Annotatsiya: Qum ko‘chishi va qum bo‘ronlari qurg‘oqchil hududlardagi avtomobil yo‘llari uchun ko‘rish masofasining qisqarishi, qoplama sirtining ishqalanish xususiyatlari pasayishi va ekspluatatsion xarajatlarning oshishi bilan bog‘liq kompleks xavf tug‘diradi [1], [2]. So‘nggi baholashlarga ko‘ra, quruq hududlar Yer quruqligining 40,6 % ini egallaydi, qum va chang bo‘ronlari esa 150 dan ortiq mamlakatdagi taxminan 330 mln aholiga ta’sir qiladi [1], [3]. Mazkur tezisda avtomobil yo‘llarida qum ko‘chishi uchun xavfli zonalarni aniqlash va besh toifada hududlashtirishda sun’iy intellekt (SI), masofadan zondlash va GIS integratsiyasiga asoslangan yondashuv taklif qilinadi. Sentinel-1/2, Landsat, ERA5-Land, DEM va yo‘l geometriyasi ma’lumotlarini birlashtirish orqali yo‘l uchastkalari bo‘yicha xavf ehtimolini dinamik baholash mumkinligi ko‘rsatildi. Adabiyotlar tahlili RF modeli uchun 96,2 % AUC, SVM uchun 0,94 AUC va desert yo‘llarini ajratishda U-Net uchun 89 % gacha IoU natijalarini qayd etadi [5], [6], [7]. Natijada O‘zbekistonning qurg‘oqchil hududlardan o‘tuvchi yo‘llar va ularga tutash xavf zonalari uchun monitoring, profilaktika va investitsiya ustuvorliklarini asoslashga xizmat qiluvchi amaliy hududlashtirish sxemasi ishlab chiqildi.

Kalit so‘zlar: qum ko‘chishi, xavfli zona, hududlashtirish, sun’iy intellekt, GIS, masofadan zondlash, avtomobil yo‘li, Sentinel-1, Random Forest, U-Net

1. Kirish

Hozirgi kunda global iqlim o‘zgarishlari, antropogen omillar hamda cho‘llanish jarayonlarining kuchayishi natijasida qum ko‘chishi hodisalari tobora dolzarb muammolardan biriga aylanib bormoqda. Ayniqsa, cho‘l va yarim cho‘l hududlarida joylashgan avtomobil yo‘llarida shamol ta’sirida qum massalarining harakatlanishi yo‘l infratuzilmasining barqaror ishlashiga jiddiy xavf tug‘diradi. Bu esa transport harakati xavfsizligini pasaytiradi, yo‘l qoplamasining tez buzilishiga olib keladi hamda ekspluatatsiya xarajatlarini sezilarli darajada oshiradi.

O‘zbekiston Respublikasining katta qismi, xususan, Qizilqum cho‘li hududlari qum ko‘chishi jarayonlariga yuqori darajada moyil bo‘lib, bu yerda joylashgan avtomobil yo‘llarini himoya qilish masalasi alohida ahamiyat kasb etadi. Shu bois, qum ko‘chishi xavfi yuqori bo‘lgan hududlarni aniqlash, ularni ilmiy asosda baholash va hududlashtirish zarurati yuzaga kelmoqda.

An’anaviy usullar yordamida bunday xavf zonalarini aniqlash ko‘p vaqt talab qiladi hamda yuqori aniqlikni ta’minlay olmaydi. Shu nuqtai nazardan, zamonaviy geografik axborot tizimlari (GIS) va sun’iy intellekt texnologiyalaridan foydalanish muammoni samarali hal etish imkonini beradi. GIS texnologiyalari orqali fazoviy ma’lumotlarni yig‘ish, qayta ishlash va tahlil qilish, turli tabiiy omillarni (relyef, shamol tezligi va yo‘nalishi, yer qoplami, namlik va boshqalar) kompleks baholash imkoniyati yaratiladi. Sun’iy intellekt esa ushbu ma’lumotlar asosida xavf darajasini prognoz qilish va avtomatlashtirilgan tarzda hududlashtirishni amalga oshirishda muhim rol o‘ynaydi.

An’anaviy qum xavfi baholash usullari ko‘pincha ekspert mulohazasi va punktual dala kuzatuvlariga tayanganligi sababli fazoviy aniqlik hamda yangilanib borish tezligi yetarli emas [4]. Vaholanki, shamol tezligi, qum manbai turi, vegetatsiya qoplami, quruqlik darajasi va yo‘lning shamol yo‘nalishiga nisbatan orientatsiyasi tez o‘zgaradigan omillar hisoblanadi. Xususan, qum bilan qoplangan qoplama sirtida ishqalanish koeffitsienti kamayadi, haydovchining chetlab o‘tish manevri esa ayniqsa ko‘rish masofasi 100 m dan pastga tushganda keskin yomonlashadi [9], [10].

Shu sababli tadqiqotning maqsadi – ochiq kosmik, meteorologik va yo‘l-geometrik ma’lumotlarga tayangan holda qum ko‘chishi xavfini avtomatik aniqlaydigan va yo‘l uchastkalarini "juda past – past – o‘rta – yuqori – juda yuqori" toifalarda xaritalaydigan SI asosidagi hududlashtirish yondashuvini asoslashdan iborat. Taklif etilayotgan sxema O‘zbekistonning Qizilqum, Ustyurt va Amudaryo quyi oqimi bilan tutash yo‘l yo‘laklari uchun pilot joriy etishga mosdir.

2. Tadqiqot metodologiyasi

Hududlashtirish birligi sifatida 0,5-1,0 km uzunlikdagi yo‘l segmentlari qabul qilinadi. Har bir segment uchun tabiiy, texnogen va geometrik ko‘rsatkichlar yig‘iladi: o‘rtacha shamol tezligi, ustun shamol yo‘nalishi, qumli yer turi, NDVI/FVC, quruqlik indeksi, yo‘lning shamolga nisbatan burchagi, gorizontal hamda vertikal egrilik radiuslari, relyef va tarixiy qum qoplanishi izlari [4], [7].

1-jadval

SI asosidagi hududlashtirish uchun asosiy ko‘rsatkichlar va ma’lumot manbalari

Ko‘rsatkich	Mazmuni	Ma’lumot manbasi	Modeldagi roli
Shamol rejimi	tezlik va yo‘nalish	ERA5-Land, meteo stansiya	xavf boshlovchi omil
Qum manbai	ko‘chuvchi/tekis/ mustahkam qum	Sentinel-2, Landsat, dala kuzatuvi	manba intensivligi
Vegetatsiya	NDVI yoki FVC	Sentinel-2	barqarorlashtiruvchi omil
Quruqlik	TVDI/LST asosli indeks	RS + meteorologiya	sirt erodibilligi
Yo‘l geometriyasi	o‘q yo‘nalishi, egri radiuslar	OSM, loyiha pasporti	ta’sirchanlik
Relyef	slope, mikroformalar	SRTM/ASTER GDEM	akumulyatsiya zonasi

Ushbu ishda avtomobil yo‘llari hududida qum ko‘chishi xavfini aniqlash va baholash uchun bir nechta zamonaviy ilmiy usullar qo‘llanildi. Tadqiqot davomida geografik axborot tizimlari (GIS) tahlili asosiy vosita sifatida ishlatilib, fazoviy ma’lumotlarni yig‘ish, qayta ishlash va tahlil qilish ishlari amalga oshirildi. GIS yordamida turli omillar – relyef, yer qoplami, shamol ko‘rsatkichlari va yo‘lga yaqinlik darajasi o‘zaro bog‘liq holda tahlil qilindi.

Masofadan zondlash (remote sensing) usullari orqali yer yuzasining holati haqida aniq va dolzarb ma’lumotlar olindi. Xususan, sun’iy yo‘ldosh ma’lumotlari asosida yer qoplami (LULC) aniqlanib, qumli va ochiq hududlar ajratib olindi. Bu esa qum ko‘chishi ehtimoli yuqori bo‘lgan zonalarni aniqlashda muhim ahamiyat kasb etdi.

Raqamli balandlik modeli asosida geomorfologik tahlil usullari qo‘llanilib, qiyalik (slope) va ekspozitsiya (aspect) ko‘rsatkichlari hisoblab chiqildi. Ushbu ko‘rsatkichlar orqali relyefning shamol yo‘nalishi va qum harakatiga ta’siri baholandi.

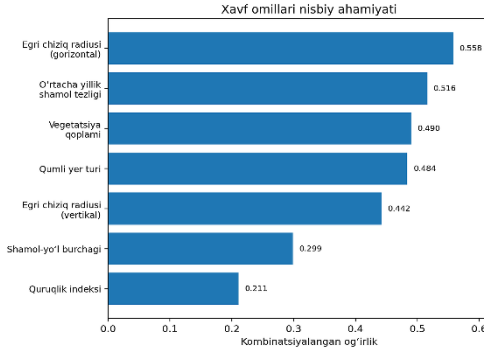
Ko‘p mezonli baholash (MCDA) usuli yordamida turli omillar bir tizimga keltirilib, ularning har biriga muhimlik darajasiga qarab og‘irlik koeffitsiyentlari berildi. Natijada umumiy xavf indeksi hisoblanib, hududlar xavf darajasiga ko‘ra guruhlarga ajratildi.

Shuningdek, statistik tahlil usullaridan foydalanilib, omillar o‘rtasidagi bog‘liqlik darajasi o‘rganildi. Ayrim hollarda regressiya tahlili yordamida qum ko‘chishi jarayoniga ta’sir etuvchi asosiy omillar aniqlashtirildi.

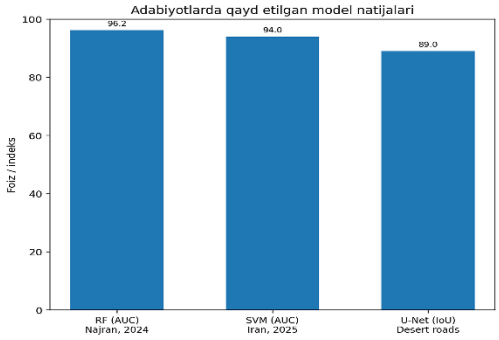
Bundan tashqari, sun’iy intellekt usullari, xususan mashinaviy o‘rganish algoritmlari qo‘llanilib, mavjud ma’lumotlar asosida qum ko‘chishi ehtimolini prognozlash amalga oshirildi. Ushbu yondashuv xavf zonalarini yanada aniqroq va ishonchli baholash imkonini berdi.

Natijada qo‘llanilgan usullar majmuasi avtomobil yo‘llarida qum ko‘chishi xavfini kompleks baholash, hududlashtirish va ilmiy asoslangan xulosalar chiqarishga xizmat qildi.

Model bosqichida RF, XGBoost/LightGBM va SVM klassifikatorlari xavf toifalarini baholash uchun, U-Net esa yo‘l va qum bosgan yuzalarni tasvirdan ajratish uchun qo‘llanadi [5]–[7]. *Random Forest (RF)* ko‘p sonli qaror daraxtlari ansambli bo‘lib, omillar o‘rtasidagi nolinear bog‘lanishlarni barqaror ushlaydi va xavfli hamda nisbatan xavfsiz segmentlarni ishonchli ajratishga xizmat qiladi. *XGBoost va LightGBM* gradient boosting oilasiga mansub modellar bo‘lib, atributlar o‘rtasidagi murakkab o‘zaro ta’sirlarni tez o‘rganadi hamda katta hajmdagi fazoviy atributlar bilan ishlashda yuqori samaradorlik beradi. *SVM* esa yuqori o‘lchamli fazoda optimal ajratuvchi chegara qurishi sababli sinflar chegarasi noaniq bo‘lgan qum migratsiyasi masalalarida foydalidir. *U-Net* semantik segmentatsiya arxitekturasi sifatida yo‘l qoplamasi va qum bilan qoplangan maydonlarni piksel darajasida ajratib, xavf zonalarining konturini aniq belgilash imkonini beradi. Baholash mezonlari sifatida AUC, F1, IoU va makoniy izchillik ko‘rsatkichlari olinadi. Bunda *AUC* modelning xavfli va xavfsiz zonalarni ajratish qobiliyatini, *F1* aniqlik va to‘liqlik o‘rtasidagi muvozanatni, *IoU* esa prognoz qilingan hududlarning real xavf zonalari bilan fazoviy moslik darajasini ifodalaydi; ayniqsa F1 ko‘rsatkichi xavfli segmentlar ulushi kam bo‘lgan ma’lumotlarda modelning amaliy ishonchliligini baholashda muhimdir. Yakuniy xavf balli tabiiy omillar, yo‘lning ta’sirchanligi va real ekspluatatsion zaiflikni birlashtirgan kompozit indeks sifatida hisoblanadi [4].



1-rasm. Li va boshq. [4] bo‘yicha indikatorlar kombinatsiyalangan og‘irligi



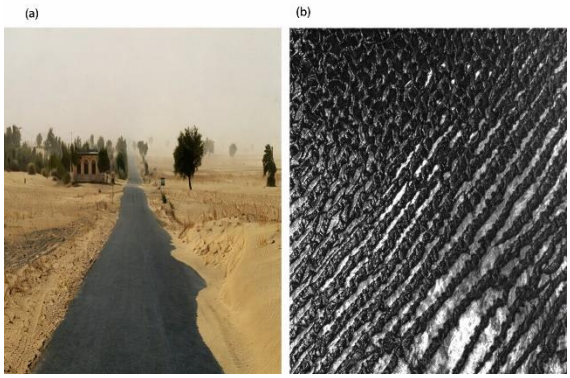
2-rasm. RF, SVM va U-Net bo‘yicha adabiyotlarda qayd etilgan model natijalari [5]–[7]

3. Natija va muhokamalar

So‘nggi ishlar qum xavfini faqat tabiiy omillar bilan emas, balki yo‘lning geometrik va ekspluatatsion xususiyatlari bilan birga ko‘rib chiqish zarurligini ko‘rsatmoqda. Li va boshq. [4] shamol tezligi, qumli yer turi, vegetatsiya, quruqlik, shamol-yo‘l burchagi hamda egri radiuslar asosida besh toifali xavf xaritasini tuzib, yuqori va juda yuqori xavf ko‘proq siljiydigan dyunalar, siyrak vegetatsiya va kam yog‘inli zonalarda jamlanishini aniqladi. Ushbu natija yo‘l segmentlari bo‘yicha real vaqtga yaqin monitoringni yo‘lga qo‘yish uchun SI modellarini joriy etish zarurligini tasdiqlaydi.

Najran shahri atrofidagi qurg‘oqchil hududlarda RF modeli 96,2 % AUC ko‘rsatkichiga erishgani, Sharqiy Eronda esa SVM modeli 0,94 AUC bilan eng samarali bo‘lgani tasviriy va spektral omillar qum migratsiyasini yuqori aniqlik bilan ajratishi mumkinligini ko‘rsatdi [5], [6]. Mazkur AUC qiymatlari 1 ga yaqinlashgani sari modelning xavfli va xavfsiz holatlarni ajratish sifati ortishini anglatadi; shu bois RF va SVM natijalari amaliy hududlashtirish uchun yuqori diskriminativ salohiyat mavjudligini ko‘rsatadi. Stewart va boshq. [7] Sentinel-1 SAR ma’lumotlari asosida desert yo‘llarini segmentatsiya qilishda ayrim hududlarda 89 % gacha IoU natijasiga erishgan. Bu yerda IoU ning yuqori bo‘lishi model tomonidan ajratilgan yo‘l va qum konturlari real tasvir bilan katta darajada ustma-ust tushganini bildiradi, ya’ni segmentatsiya xaritalari yo‘l ekspluatatsiyasi uchun yetarlicha ishonchli fazoviy asos yaratadi. Demak, xavfli zonalarni hududlashtirishda optik va radar ma’lumotlarini birgalikda ishlatish eng maqbul yo‘l hisoblanadi.

Taklif etilayotgan amaliy mezonlar quyidagicha: shamol tezligi 6,5 m/s dan yuqori bo‘lgan, ko‘chuvchi dyunalar mavjud, vegetatsiyasi siyrak, quruqlik indeksi past, ustun shamol yo‘nalishi yo‘l o‘qiga 60-90° burchak ostida kesishadigan va kichik radiusli egri chiziqlar joylashgan segmentlar "juda yuqori" xavf toifasiga ustuvor ravishda kiritiladi [4]. Bunday uchastkalarda mexanik to‘siqlar, yashil himoya polosalari, patrul tozalash grafiklari va ogohlantiruvchi axborot tizimlari birgalikda rejalashtirilishi lozim. Bundan tashqari, Kumtag sahrosida 2100 yilga borib dyuna migratsiya tezligining 19,61 m/yilgacha oshishi prognoz qilinganligi iqlim o‘zgarishi sharoitida oldindan rejalashtirishni kuchaytirish zarurligini ko‘rsatadi [8].



3-rasm. (a) Qum bosayotgan avtomobil yo‘li ko‘rinishi, Noorpur Thal, Pokiston (Vasiq Eqbal, Wikimedia Commons, CC BY-SA 4.0); (b) Rub’ al Khali dyuna maydonining Sentinel-1 radar tasviri va yo‘l izlari (ESA/Copernicus, CC BY-SA 3.0 IGO)

4. Xulosa

SI, GIS va masofadan zondlash integratsiyasi qum ko‘chishi xavfini statik emas, balki davriy yangilanadigan makoniy boshqaruv mahsulotiga aylantiradi. Tahlil natijalari shamol tezligi, vegetatsiya, qum manbai turi va yo‘l geometriyasi xavfli zonalarni hududlashtirishda tayanch omillar ekanini ko‘rsatdi [4]–[7]. Shu bois RF va gradient boosting asosidagi klassifikatorlar xavf toifalash bosqichida, U-Net esa fazoviy segmentatsiya bosqichida o‘zaro to‘ldiruvchi model juftligi sifatida qaralishi mumkin; bunday kombinatsiya yo‘l xizmatlariga ham balli xavf bahosi, ham aniq fazoviy kontur beradi. O‘zbekiston sharoitida bunday tizim A380 va qurg‘oqchil mintaqalardagi boshqa magistrallarda pilot tarzda joriy etilib, yo‘l ekspluatatsiyasi xarajatlarini kamaytirish, avariya xavfini pasaytirish va himoya inshootlarini aniq uchastkalarga yo‘naltirish imkonini beradi.

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Ensuring the priority of public transport and traffic safety in Tashkent

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Abstract: This study examines the issues of ensuring road traffic safety in the public transport system of Tashkent city and creating a convenient and safe environment for pedestrians. It also analyzes the directions for the comprehensive development of public transport, the provision of high-quality and safe transport services to passengers, and the improvement of transport infrastructure. The paper highlights modern methods and effective solutions for enhancing traffic safety in public transport.

Keywords: public transport, traffic safety, road accidents, passenger vehicles, routes, buses, statistical observation, interviews, pedestrian traffic, traffic flow

Toshkent shahrida jamoat transporti ustuvorligi va harakat xavfsizligini ta'minlash

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Annotatsiya: Toshkent shahar jamoat transporti tizimida yo’l harakati xavfsizligini ta’minlash hamda piyodalarga qulay harakatlanish muhitini yaratish maqsadida kompleks rivojlantirish, yo’lovchilarga sifatli va xavfsiz transport xizmatlarini ko’rsatish va transport infratuzilmasini takomillashtirishdan iborat. Shu bilan birga jamoat transportida harakat xavfsizligini ta’minlash.

Kalit so‘zlar: jamoat transporti, harakat xavfsizligi, yo’l-transport hodisalari, yo’lovchi tashuvchi transport vositasi, yo’nalishlar, avtobuslar, statistik kuzatish, intervyu, piyodalar harakati, transport oqimini

1. Kirish

O’zbekiston Respublikasi Prezidentining 4 aprel 2022 yil 190-sonli “Avtomobil yo’llarida inson xavfsizligini ishonchli ta’minlash va o’lim holatlarini keskin kamaytirish chora-tadbirlari to’ğrisida”gi hamda 2 fevral 2022 yil 111-sonli “Toshkent shahar jamoat transporti tizimini yanada rivojlantirishga doir qo’šimcha chora-tadbirlar to’ğrisida”gi qarorlari Toshkent shahar yer usti jamoat transporti tizimini kompleks rivojlantirish, yo’lovchilarga sifatli va xavfsiz transport xizmatlarini ko’rsatish, transport infratuzilmasini yaxshilash, harakat tarkibini barcha qulayliklarga ega bo’lğan zamonaviy avtobuslar bilan yangilash, yo’l harakati xavfsizligini ta’minlash hamda piyodalarga qulay harakatlanish muhitini yaratish maqsadida soha mutaxassislari oldiga qator vazifalar yuklandi [1,2].

2. Tadqiqot metodologiyasi

Toshkent shahar yer usti jamoat transporti tizimida yo‘lovchilar xavfsizligini ta’minlash bo‘yicha hukumatimiz tomonidan qator talablar qo‘yilgan. Yo‘lovchilarni tashish jarayonida ularning xavfsizligini ta’minlash javobgarligi haydovchilar zimmasida bo‘ladi. Lekin yo‘lovchilarni tashish jarayonida ularning xavfsizligini ta’minlash uchun aniq tadbirlar belgilashda asosiy tayanch ko‘rsatma sifatida harakat xavfsizligi ko‘rsatkichlarini har taraflama chuqur va obyektiv tahlil qilish natijalaridan olingan xulosalardan foydalaniladi: yo‘lovchilarning harakat xavfsizligiga taalluqli «Avtomobil-haydovchi-yo‘l-piyoda-muhit» tizimiga kiruvchi har bir omilning faoliyatiga tegishli tadbir va choralar ishlab chiqish uchun; biron-bir boshqaruv territoriyasidagi, vazirliklardagi va ularning korxonalaridagi falokatlar ahvolini, o‘zgarish mohiyatini hamda istiqboldagi o‘zgarishini bashorat qilish va harakat xavfsizligini ta’minlash bo‘yicha tadbirlar ishlab chiqish kerak. Yo‘lovchilar majburiyatlarini va qo‘yilgan talablarni bajarmasliklari oqibatida yo‘l-transport hodisalari (YTH)ning sodir bo‘lishini amaliyot isbotlagan. Ammo yo‘lovchi tashuvchi transport vositasi YTHni sodir etganda yoki uning ishtirokchisiga aylanganda ham yo‘lovchilar katta jismoniy va ma’naviy talafot ko‘rishadi. Shu sababli ham yo‘lovchi tashuvchi transport vositasi qaysi transport korxonasiga tegishli bo‘lsa, shu korxonada harakat xavfsizligi ko‘rsatkichlarini o‘rganish va tegishli tadbirlar ishlab chiqish yo‘lovchilar xavfsizligini ta’minlashning asosiy mezonlaridan belgilanadi.

Toshkent shahrida yer usti jamoat transportida yo‘lovchilarni tashish avtobus, yo‘nalishli va yo‘nalishsiz taksilarda amalga oshirilmoqda.

Shaharda mulkchilikning turli shakllaridagi 468 ta tashuvchi tomonidan yo‘lovchilarni tashish xizmatlari ko‘rsatilmoqda, shundan 13 ta korxona, jumladan, 8 ta davlat ulushi bo‘lgan korxona avtobus yo‘nalishlarida, 55 ta korxona yo‘nalishli taksi yo‘nalishlarida va 400 ta korxona yo‘nalishsiz taksilarda xizmat ko‘rsatmoqda.

Jamoat transportining o‘zaro bog‘liqligini ta’minlash uchun xizmat qilayotgan 5 ta transport-o‘tish bog‘lamasi mavjud.

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2005 ta avtobus oraliq bekati mavjud bo‘lib, 166 yo‘nalishda xizmat ko‘rsatadi. Velosiped transporti foydalanuvchilari uchun 12 ta ko‘chada 100 km uzunlikdagi velosiped yo‘laklari mavjud.

Yo‘lovchilarga yo‘nalishsiz taksi xizmati 11 000 dan ortiq litsenziyaga ega yengil avtomobillarda ko‘rsatilib kelinmoqda.

2025-yil 1-yanvardan yo‘lkira haqi to‘lovining avtomatlashtirilgan tizimi joriy etilib, 100 foiz yo‘lovchilar ushbu tizimdan foydalanmoqda. Mazkur tizim doirasida 5, 10, 15, 20 va 30 kunlik hamda imtiyozli oylik tarif rejalari joriy etilgan.

Avtomatlashtirilgan dispetcherlik boshqaruvi (ASDUM) tizimi joriy etilib, ushbu tizim orqali avtobuslar harakatini onlayn, oraliq bekatlardagi to‘xtash vaqti, yo‘nalishdagi harakat tezligi, avtobuslar oraliq masofasini, ya’ni intervalni nazorat qilish imkoniyati mavjud.

Yo‘nalishlar va ularda harakatlanayotgan avtobuslar to‘g‘risida ma’lumot olish, manzilga yetib olishning optimal yo‘nalishini belgilash kabi qulayliklarga ega bo‘lgan «Toshkent transporti» mobil ilovasi ishga tushirilgan.

Shaharda 4 mingdan ortiq ko‘cha mavjud bo‘lib, ularning uzunligi 5 900 km, shundan avtomagistrallar — 462 km, asosiy ko‘chalar — 445 km, shoh ko‘chalar — 464 km, halqa ko‘chalar — 1 481 km, ishlab chiqarish hududlaridagi ko‘chalar — 145 km va mahalliy ahamiyatdagi ko‘chalar — 2 896 kilometrni tashkil etmoqda.

Shaharda avtomobil transporti vositalari soni 497 360 tani tashkil etib, hududlardan kuniga o‘rtacha 165 mingdan ortiq avtotransport vositalari kirib-chiqmoqda.

Toshkent shahrida 600 dan ziyod yirik chorrahalar va 40 mingta yo‘l belgilari mavjud bo‘lib, ular yordamida transport va piyodalar harakati tartibga solinadi. 115 ta svetofor yagona raqamlashtirilgan markaz tomonidan boshqarilmoqda.

Statistik kuzatish birlamchi statistik ma’lumotlarni to‘plash va o‘rganilayotgan obyekt bilan bog‘liq barcha muhim faktlarni ilmiy jihatdan tashkillashtirilgan qayd etishni o‘z ichiga oladi. Statistik kuzatish — bu ijtimoiy hodisalarni tavsiflovchi faktlar va ularning xususiyatlarini yagona, ishlab chiqilgan dastur bo‘yicha ilmiy asoslangan qayd etish, ommaviy ma’lumotlarni to‘plash.

Intervyu — jamoat transportidan foydalanish sabablari va tirbandliklarga munosabatni tahlil qilish uchun har tomonlama va sifatli ma’lumot to‘plash hamda aholi, jumladan, haydovchilarning fikr va takliflarini o‘rganish uchun ijtimoiy-iqtisodiy tadqiqotning mutlaqo maqbul usuli bo‘lgan suhbat orqali amalga oshiriladi. Ushbu intervyu usulining o‘ziga xos xususiyati shundaki, u mavzuga bir xil darajada qiziqqan ikki kishi o‘rtasida jonli va norasmiy suhbatni o‘z ichiga oladi. Suhbatdosh va respondent o‘rtasidagi to‘g‘ridan-to‘g‘ri aloqa anketalar orqali olish qiyin bo‘lgan ma’lumotlarni olish uchun ko‘plab afzalliklarni beradi.

Toshkent shahri aholisining tirbandlikka, jamoat transportiga munosabati va uni kamaytirish bo‘yicha takliflarini o‘rganish maqsadida ijtimoiy so‘rov tashkil etildi [14].

Unda jami 891 kishi ishtirok etdi. Ishtirokchilarning 60,8 foizini avtomobil haydovchilari tashkil etdi. Shundan 10,3 foizi ayollardir.

So‘rov natijasida quyidagilar aniqlandi:

1. Avtomobil boshqarmasligini ta’kidlagan ishtirokchilarning:

41,8 foizi avtobus,
27,5 foizi metro,
24,1 foizi taksi,
1,7 foizi mikroavtobus xizmatidan foydalanishini,
4,9 foizi piyoda yurishini bildirgan.

Jamoat transportidan ko‘proq ayollar (33,1%) va yoshlar (36,5%), shaxsiy transportdan erkaklar (33,1%) foydalanishi ma’lum bo‘ldi.

Bildirilgan fikrlar orasida jamoat transporti, ya’ni avtobuslar uchun infratuzilmalarni yaxshilash, parkovkalarni to‘g‘ri shakllantirish, ko‘pqavatli avtoturargohlar, piyodalar uchun yerosti o‘tish yo‘llari va ko‘priklar qurish, metro liniyalarini kengaytirish, yo‘l harakati qoidalariga qat’iy amal qilinishini ta’minlash, raqamli boshqaruvga o‘tish kabi takliflar ko‘p uchraydi.

Toshkent shahar yer usti jamoat transport tizimidagi harakat xavfsizligini ta’minlashda quyidagi muammolar mavjud:

1. Toshkent shahrida transport oqimini boshqarish, jamoat transporti uchun chorrahalar o‘tkazuvchanlik qobiliyatini oshirish bo‘yicha monitoring-tahlil ishlarini olib borish.
2. Toshkent shahrida yer usti jamoat transporti haydovchilarining mehnatini to‘g‘ri tashkil etish.
3. Yer usti jamoat transportida harakat xavfsizligi sohasi uchun kadrlar, ya’ni harakat xavfsizligi mutaxassislari, haydovchilarni tayyorlash va ularning malakasini oshirish tizimini yanada takomillashtirish.
4. Yo‘lovchilarga yer usti jamoat transportidan foydalanishning xavfsiz harakatlanish qoidalarini o‘rgatish.
5. Toshkent shahrida mavjud barcha chorrahalarni yo‘l harakatini boshqarishning avtomatlashtirilgan boshqaruv tizimiga integratsiya qilish.
6. Toshkent shahrida yer usti jamoat transporti yo‘l harakatini tashkil etish tizimining mukammal emasligi sababli yo‘llar va chorrahalarda transport oqimi to‘g‘ri taqsimlanmagan hamda tirbandliklar darajasi yuqori, yo‘l-transport hodisalari soni ortib bormoqda.
7. Asosiy magistral yo‘nalishlarda transport harakatini tartibga solish choralarini amalga oshirish, ya’ni jamoat transporti harakatiga ustuvorlik berish, yo‘l belgilari va ko‘rsatkichlarini o‘rnatish.
8. Yo‘lovchi tashish bilan band bo‘lgan xususiy tashuvchilarning harakat xavfsizligini ta’minlash muammolarini o‘rganish.
9. Toshshahartransxizmat AJ filiallarida harakat xavfsizligi faoliyatini tashkil etilishini baholash.
10. Toshkent shahrida yer usti jamoat transporti marshrutlarining harakat xavfsizligi talablariga mutanosibligi.
11. Toshkent shahrida yer usti jamoat transportidan foydalanuvchi yo‘lovchilar oqimi va ularning jamoat transportiga ehtiyojida harakat xavfsizligi talablarini o‘rganish.
12. Toshshahartransxizmat AJ filiallarida harakat xavfsizligini ta’minlashda harakat xavfsizligi xizmati faoliyatini korxonaning boshqa bo‘limlari faoliyati bilan muvofiqlashtirish.
13. Toshkent shahrida yer usti jamoat transporti marshruti yo‘nalishida avtomobillarning yo‘l bo‘yi pullik to‘xtash joylari tizimini tashkil etish.
14. Avtobus oraliq bekatlari infratuzilmasining xavfsizlik, qulaylik va shaharsozlik me’yorlariga mosligini baholash.
15. Toshkent shahrida yer usti jamoat transportining o‘rtacha harakatlanish tezligining yo‘lovchilarni tashish jarayonidagi harakat xavfsizligi talablariga mutanosibligi.
16. Toshkent shahar yer usti jamoat transporti tizimida harakat xavfsizligini ta’minlashda raqamli texnologiyalarni joriy etish.

3. Xulosa

Aniqlangan muammolarni hal qilish uchun Toshkent shahar jamoat transporti tizimida yo‘l harakati xavfsizligini ta’minlashning quyidagi ustuvor yo‘nalishlari belgilandi:

-Toshkent shahrida transport oqimini boshqarish, jamoat transporti uchun chorrahalar o‘tkazuvchanlik qobiliyatini oshirish bo‘yicha monitoring-tahlil ishlarini olib borish, takliflarni ishlab chiqish va ularni joriy etish

- Yo‘lovchi tashish bilan band bo‘lgan xususiy tashuvchilarning muammolarini o‘rganish va takliflar ishlab chiqish.

-Avtomobillarning avtomatlashtirilgan yo‘l bo‘yi pullik to‘xtash joylarini tashkil etish.

- Shahar ko‘chalari kesishmasida piyodalar va velosiped harakati xavfsizligini ta’minlovchi texnik vositalarni joriy etish.

- Shahar ko‘chalarining har bir yo‘nalishida uch va undan ortiq harakat polosalar mavjud bo‘lganda, harakat yo‘nalishlarini ajratuvchi xavfsizlik orolchalarni tashkil etish.

- Piyoda va velosiped yo‘laklarini tashkil etishda, xalqaro tajribalarni hisobga olish, chorraxalar bilan kesishmalarda xavfsiz va to‘siqsiz muhitni yaratish.

- Piyodalar harakatlanishi uchun ustuvorlik berish

- Transport oqimini oqilona boshqarish va tirbandliklarni kamaytirish bo‘yicha chorrahalar va ko‘chalar kesimida loyihalar ishlab chiqish;

-Soha bo‘yicha sifatli kadrlar tayyorlanib, harakat xavfsizligini ta’minlashni takomillashtiriladi;

-Yer usti jamoat transporti haydovchilari malakalarini oshirishning innovatsion metodlari taqdim etiladi, YHQ buzilishi va YTH lar soni keskin kamayadi;

-Yo‘nalishdagi avtobuslarning o‘rtacha tasarruf tezligini oshiriladi;

-Avtobus qatnovlari muntazamligi ko‘tariladi;

-Yo‘nalish harakat intervali qisqartiriladi;

-Shahar hududini jamoat transporti bilan to‘liq qamrab olinadi va harakat xavfsizligini ta’minlanadi;

-Jamoat transportining jozibadorligini oshirishda harakat xavfsizligi ko‘rsatkichlarini oshiriladi;

-Jamoat transporti qulay va ekologik toza harakat tarkibi bilan yangilansa, atrof-muhitga salbiy ta’siri kamayadi;

-Shahar markazida harakatlanayotgan engil avtomobillar sonining qisqartirilishi mezanizmida harakat xavfsizligini ta’minlash ko‘rsatkichlarini qo‘llaniladi;

-Velosiped transporti infratuzilmasining keng rivojlanishi imkoniyati yaratiladi.

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Project-based thinking and psychological-pedagogical disciplines: bridging theory and practice in higher education

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Abstract: In this paper, the importance of psychological and pedagogical disciplines — psychology, pedagogy, social psychology, developmental psychology, and pedagogical acmeology — is substantively examined as a fundamental and system-forming basis for students' professional development and the formation of their project-based thinking in higher education. It is shown that these disciplines are not an optional addition to the curriculum, but constitute its internal core, giving the educational process meaningfulness and a human-centered dimension.

Keywords: psychological-pedagogical disciplines, pedagogical acmeology, developmental psychology, project-based activity, soft skills, competence-based approach, critical thinking, professional development, higher education

Проектное мышление и психолого-педагогические дисциплины: мост от теории к практике в высшем образовании

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Аннотация: В данной работе аргументированно раскрывается значение психолого-педагогических дисциплин — психологии, педагогики, социальной психологии, возрастной психологии и педагогической акмеологии — как фундаментальной, системно организующей основы профессионального становления студентов и развития их проектного мышления в условиях высшей школы. Показано, что эти дисциплины не являются факультативным дополнением к учебному плану, но составляют его внутренний стержень, придающий образовательному процессу осмысленность и человеческое измерение.

Ключевые слова: психолого-педагогические дисциплины, педагогическая акмеология, возрастная психология, проектная деятельность, soft skills, компетентностный подход, критическое мышление, профессиональное развитие, высшее образование

1. Введение

Как показывают многолетние наблюдения, современное высшее образование переживает не только период перемен, но и внутренне значимый, а во многом и судьбоносный период переосмысления собственных основ: прежняя, казалось бы, непоколебимая ориентация на подготовку узкоспециализированных технических специалистов постепенно уступает место более сложным и требовательным социальным запросам — к людям, способным понимать других, принимать по-настоящему ответственные решения и сохранять профессиональную стабильность в условиях неопределенности. Эти изменения отражают не только смену приоритетов, но и возвращение к подлинно гуманистическому смыслу образования.

В свете этих изменений центральную роль играют психологические и педагогические дисциплины – они переходят из формального дополнения к учебному плану в его сущность. Эти дисциплины наполняют процесс глубоким смыслом, целенаправленностью и гуманистическим измерением, раскрывают психологические принципы педагогической деятельности и обеспечивают гармоничное развитие личности. Без них профессиональный рост теряет свою сложность, одномерность и практическую надежность и не может создать условия для подготовки стабильных специалистов.

Психология, педагогика, социальная психология, психология развития и педагогическая педагогика — это не просто набор академических дисциплин, а внутренне взаимосвязанный, концептуально целостный свод научных знаний о человеке — о микромоделях развития личности, механизмах её формирования в академической среде.

Масштабные реформы высшего педагогического образования в Узбекистане действительно актуальны: с 2017–2020-х годов внедряется новая система, включая модернизацию Национального педагогического университета им. Мукими (Ташкент), с акцентом на цифровизацию и компетентностный подход. Глобальная технократизация образования — реальный тренд (Болонский процесс, STEM-приоритет), часто маргинализирующий психолого-педагогические дисциплины. [1]. Между тем исследования Гарвардского университета, Фонда Карнеги и Стэнфордского исследовательского центра свидетельствуют: 85% профессионального успеха специалиста определяется «мягкими» навыками, тогда как технические компетенции обеспечивают лишь 15% этого успеха [2].

Цель данной статьи состоит не только в формальном обозначении исследовательской задачи, но и, позволю себе подчеркнуть, в её внутреннем теоретическом осмыслении: обосновать роль психолого-педагогических дисцип-лин как фундаментальной основы формирования проектного мышления и становления профессиональной зрелости студентов высшей школы, рассматривая этот процесс как сложное, многослойное движение от усвоения знаний к их личностному и ценностному присвоению.

2. Методология исследования

В рамках исследования проведён системный анализ научной литературы по психологии, педагогике и акмеологии, представленной в авторитетных базах данных (КиберЛенинка, Scopus, Web of Science); источники отбирались с учётом их теоретической значимости, методоло-гической обоснованности и способности раскрывать сущностные характеристики изучаемых процессов. Одновременно использовалось теоретическое моделиро-вание структуры психолого-педагогических компетен-ций, направленное на выявление их внутренней логики, взаимосвязей и динамики формирования. Допол-нительное аналитическое измерение обеспечивал компаративный анализ зарубежного и отечественного опыта, позволяющий рассматривать проблему в более широком научном и культурном контексте.

Методологическую основу состав-ляют четыре подхода: деятельностный (А. Н. Леонтьев, С. Л. Рубинштейн), компетентностный (Дж. Равен, И. А. Зимняя) [3], конструктивистский (Л. С. Выготский, Дж. Дьюи) [4] и акмеологический (А. А. Деркач, Н. В. Кузьмина) [5]. Каждый из этих подходов позволяет раскрыть различные аспекты процесса профессионального становления студентов и развития их проектного мышления. их проектного мышления.

Для работы использовались теоретические методы (анализ и обобщение литературы, сравнительно-компаративный анализ отечественного и зарубежного опыта, моделирование структуры компетентности) и эмпирические (анкетирование, наблюдение, экспертная оценка, контент-анализ и педагогический эксперимент).

На предварительном этапе проведено пилотное анкетирование 50 студентов 3–4 курсов направления «Педагогика». Средний уровень теории составил 31,33 из 40 (78,3%), а готовность к практической проектной деятельности — 4,22 из 5 (84,4%). Выявились три проблемы: студенты плохо структурируют проекты без шаблонов, слабо взаимодействуют в команде онлайн и не умеют проверять информацию критически. Эти наблюдения легли в основу разработки формирующей модели.

Эксперимент проходил с октября по декабрь 2025 года на базе НПУ имени Низами в дисциплине «Методика преподавания предмета Воспитание». В нем участвовала группа П-302: 15 студентов заочной формы (экспериментальная) и 15 очной (контрольная). Статистическая проверка показала, что группы сопоставимы ($F_{эмп} = 1{,}194 < F_{крит} = 2{,}48$; $U_{эмп} = 105 > U_{крит} = 72$; $p = 0{,}05$).

Эксперимент был формирующим: проверялось, помогает ли использование GenAI активнее развивать проектную компетент-ность. Экспериментальная группа работала по модели «интеллек-туального партнёрства»: ИИ генерировал идеи, студенты их проверяли по трём критериям — нормативному, фактологическому и социокультурному — и адаптировали под реальную школьную практику.

Работа проходила в три этапа. На констатирующем (октябрь) определён исходный уровень компетентности (ЭГ — 34,07; КГ — 34,87; $p > 0{,}05$). На формирующем (ноябрь) студенты делали проекты в малых группах с использованием ChatGPT, Claude, Midjourney и Gemini. На заключительном этапе проводилась повторная диагностика и защита проектов.

Результаты: в экспериментальной группе средний показатель вырос с 34,07 до 43,87 (28,8%; $t = 4{,}32$; $p < 0{,}01$), в контрольной — с 34,87 до 39,13 (12,2%; $t = 2{,}15$; $p < 0{,}05$). После эксперимента различия между группами исчезли ($t_{эмп} = 0{,}69 < t_{крит} = 2{,}048$; $p > 0{,}05$), что показывает: предложенная методика действительно помогает заочникам компенсировать недостаток аудиторного времени.

3. Результаты и обсуждение

Структура и содержание психолого-педагогических дисциплин

Психолого-педагогические дисцип-лины формируют органичный научный блок, объединённый общим объектом — развивающейся личностью человека — и единой задачей: понять закономерности её развития и овладеть методами организации образовательного процесса, направленного на формирование проектных компетенций. Освоение этих дисциплин позволяет студенту не только анализировать обучающихся, но и проектировать учебные и практические задания, строить образовательные траектории, учитывать индивидуальные особенности участников и цели командной работы.

Педагогика выступает ключевым компонентом этого блока, предоставляя знания о закономерностях обучения, методах и технологиях преподавания, принципах мотивации и развития компетенций. Эти знания позволяют будущему специалисту сознательно организовывать процесс проектной деятельности, создавать условия для эффективного усвоения знаний и развития самостоятельности, критического и творческого мышления, а также целенаправленно формировать профессиональную зрелость студентов. Педагогика раскрывает закономер-ности становления личности в процессе обучения и воспитания. Как указывает Б. Т. Лихачёв, педагогика выявляет факторы, способствующие эффективному усвоению знаний, умений и способов мышления, а также механизмы выработки у обучаемых собственной системы ценностных ориентаций [6]. Именно педагогика формирует понимание «зачем» в профессиональной деятельности.

Психология выступает теорети-ческим фундаментом блока, раскрывая структуру личности, механизмы восприятия, памяти, мышления и

эмоционально-волевой сферы. Эти знания необходимы будущему специалисту для того, чтобы прогнозировать поведение людей, выстраивать адресные стратегии взаимодействия и принимать осознанные решения при организации проектной деятельности, делая её эффективной и осмысленной.

Социальная психология изучает поведение человека в группе, механизмы межличностного влияния, феномены лидерства и конфликта. В контексте проектной деятельности это означает способность управлять командными процессами и выстраивать эффективную коммуникацию внутри проектной группы.

Возрастная психология обеспе-чивает дифференцированный взгляд на развитие личности на различных этапах онтогенеза, формируя у специалиста способность адаптировать профессиональные подходы к возрастным характе-ристикам своих подопечных.

Педагогическая акмеология занимает особое место в данном блоке. Согласно А. А. Деркачу, акмеология исследует закономерности и механизмы достижения человеком вершин профессионального мастерства; её предметом выступают процессы и условия профессиональной самореа-лизации личности, начиная с профессионального самоопределения [5]. В образовательном пространстве она обеспечивает проектирование восходящей траектории развития студента — от обучаемого к самостоятельному субъекту профессиональной деятельности.

Роль в системе высшего образования

В системе высшего образования данные дисциплины выполняют четыре функции. Первая — гуманизация образовательного процесса: они переориентируют учебный процесс с формальной передачи знаний на развитие личности студента как целостного субъекта. Гуманистическая педагогика (К. Роджерс, А. Маслоу) утверждает, что подлинное развитие возможно лишь при создании атмосферы психологической безопасности и уважения к личности обучаемого [7].

Вторая функция — формирование soft skills. По данным ВЭФ «Future of Jobs» (2023), среди десяти ключевых навыков будущего семь относятся к категории soft skills: аналитическое и творческое мышление, гибкость, самоэффективность, любознательность и надёжность [8]. Психолого-педагогические дисцип-лины являются главным академическим инструментом целенаправленного формирования этих качеств.

Третья функция — развитие критического мышления. Изучение психологических механизмов познания, педагогических концепций обучения и социально-психологических закономерностей группового поведения формирует у студента инструментарий рефлексивного профессионального мыш-ления.

Четвёртая функция — подготовка к работе в сложной социальной среде. Специалист без психолого-педагогической подготовки знает «как делать», но не понимает «зачем и для кого» — что неизбежно ведёт к профессиональному формализму и утрате смысла деятельности.

Механизмы формирования проектного мышления

Психолого-педагогические дисциплины формируют основу проектного мышления через три взаимосвязанных механизма. Первый из них — проблематизация, которая возникает в процессе изучения педагогики и смежных дисциплин: студент, обладающий знаниями о закономерностях развития личности и особенностях образовательного процесса, начинает воспринимать учебную и профессиональную реальность как живое пространство человеческих потребностей, требующих осознанного профес-сионального ответа. Именно это осознание становится исходной точкой проектного мышления, формируя способность видеть проблему, ставить цели и искать пути её решения.

Целеполагание приобретает ценностное измерение благодаря педагогике и акмеологии. Первая формирует понимание смысла профессиональной деятельности через освоение теорий воспитания; вторая ориентирует студента на высшие смыслы профессиональной самореализации. Психолого-акмеологические механизмы интенсифицируют и оптимизируют процесс формирования профессионального мастерства [5].

Рефлексия как обязательный компонент проектного цикла является центральной категорией психологии и педагогической акмеологии. Согласно Ю. Н. Кулюткину, именно рефлексивное мышление отличает педагога-мастера от педагога-ремесленника [9]. Рефлексия позволяет студенту выйти за рамки исполнительской позиции и занять позицию субъекта, самостоятельно управляющего своей профессиональной траекторией.

4. Заключение

Психолого-педагогические дисциплины — психология, педагогика, социальная психология, возрастная психология и педагогическая акмеология — образуют единый блок знания о человеке и его развитии через образование. Этот блок является смысловым ядром профессиональной подготовки, а не её факультативным дополнением. Он обеспечивает гуманизацию обучения, формирование soft skills, развитие критического мышления и готовность к работе в сложной социальной среде — те качества, которые определяют 85% профессионального успеха специалиста [2].

Педагогическая акмеология превращает студента из пассивного объекта образовательного воздействия в активного субъекта собственного профессионального роста, обеспечивая восходящую траекторию его развития и формирование самостоятельного проектного мышления. Перспективы дальнейших исследований прежде всего связаны с разработкой диагностического инструментария для оценки уровня сформированности психолого-педагогических компетенций студентов в системе педагогического образования Республики Узбекистан, что позволит точнее выявлять образовательные потребности и совершенствовать методы подготовки будущих специалистов.

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Portland cement with limestone additive based on local raw materials

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Abstract: This study investigates the influence of limestone additive on the physico-mechanical and chemical properties of Portland cement produced from local raw materials. Introducing limestone in amounts of 10–20 % improves the granulometric composition of cement, enhances the workability of cement paste, reduces clinker consumption, and accelerates early hydration. Experimental results showed that at the optimal additive content, sufficient compressive and flexural strength is achieved within the standard setting periods. The results confirm the feasibility of effective use of local limestone in the production of blended Portland cements that meet modern standards, allowing clinker savings and reducing production costs.

Keywords: portland cement, limestone, mineral additive, strength, clinker, gypsum, cement hydration, mechanical strength, porosity, chemical composition

Портландцемент с известняковой добавкой на основе местного сырья

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Аннотация: В данной работе исследовано влияние известняковой добавки на свойства портландцемента, полученного на основе местного сырья. Введение известняка в количестве 10–20 % улучшает гранулометрический состав цемента, используется как активная минеральная добавка, снижает расход клинкера и способствует ускорению гидратации в период раннего твердения. Экспериментальные результаты показали, что при оптимальном содержании добавки обеспечивается достаточная прочность при сжатии и изгибе в стандартные сроки твердения. Полученные данные подтверждают возможность эффективного использования местного известняка при производстве добавочного портландцемента, что позволяет экономить клинкер и снижать себестоимость продукции.

Ключевые слова: портландцемент, известняк, минеральная добавка, прочность, клинкер, гипс, гидратация цемента, механическая прочность, химический состав

1. Введение

Решения технологических проблем, являющихся одним из важных путей развития строительных материалов на основе цемента, необходимо при его производстве решать вопросы снижения загрязнения окружающей среды, в том числе и снижать выбросы в атмосферу CO_2, выделяющегося в большом количестве при производстве цемента. Одним из путей уменьшения выбросов CO_2 в атмосферу в цементной промышленности может быть снижение расхода клинкера в цементе или введение в него при помоле некоторого количества известняка. Дальнейшее увеличение в цементе количества известняка в лучшем случае переводит его в разряд добавке, а увеличение его количества в цементе до 35 %, принятое современным ГОСТ 31108- 2020. Также было установлено, что известняк целесообразно использовать в цементе с повышенным содержанием C_3A, так как это позволяет несколько увеличить прочность цементного камня [1]. Дальнейшие исследования В.М. Колбасова, А.С. Пантелеева, В.С. Савина, Ю.М. Бутта, В.В. Тимашева и Ю.И. Бенштейна также подтвердили, что взаимодействие карбонатов кальция и магния, как правило, происходит с алюмосодержащими составляющими цемента, с образованием непрерывного ряда твердых растворов $3CaO·Al_2O_3·CaCO_3·12H_2O$ – $3CaO·Al_2O_3·3Ca(CO)_3·32·H_2O$ [2–17]. Было установлено, что в процессе твердения таких материалов вначале проявляются метастабильные образования типа $3CaO·Al_2O_3·0,25·CaCO_3·11H_2O$ – четырехкальциевого монокарбонатного гидроалюмината, а далее возможно образование даже $3CaO·Al_2O_3·3CaCO_3·(30-32)·H_2O$ – шестикальциевого трёхкарбонатного гидроалюмината, которые содержат значительное количество химически связанной воды.

2. Методология исследования

Объектом исследования является известняк месторождения «Oqtov» (Республика Каракалпакстан), используемый в качестве активной минеральной добавки к цементу. Изучены его химико-минералогический состав и физико-химические свойства.

Химический состав известняка определяли по методике ГОСТ 5382–2019; минералогию и структуру — традиционными методами физико-химического исследования (оптический — с использованием бинокулярного микроскопа B1-220A; рентгенофазовый — на дифрактометре XRD-6100).

3. Результаты и обсуждение

В связи с тем, что в месторождении «Oqtov» обнаружен значительный запас известняка (рис. 1), ранее не использовавшегося в цементной промышленности в качестве активной минеральной добавки, а на ООО «Karakalpak Cement» остро ощущается дефицит активной минеральной добавки для увеличения объема производства добавочного и пуццоланового цемента, целью настоящего исследования являлось определение пригодности данного известняка для использования в качестве минеральной добавки, а также оценка его влияния на показатели прочности портландцемента.

Рис. 1. Известняк Каракалпакстанского месторождения x100

Проба известняка, которую в работе планируется использовать как активной минеральной добавки к цементу, по химическому составу соответствует требованиям, предъявляемым O'zDSt 2950 «Материалы сырьевые для производства портландцементного клинкера. Технические условия», к химическому составу карбонатсодержащего компонента для производства портландцементного клинкера (табл. 1). Визуально известняк представлен кусковой обломочной горной породой осадочного происхождения, Цвет бело-сероватый с налетом красновато-оранжевых оттенков (рис. 1). Текстура однородная, плотная, структура низкопористая, кристаллически-зернистая. Основное вещество - карбонат кальция $CaCO_3$ в количестве 95,86%, $MgCO_3$ = 0,924% (табл. 1).

Результаты рентгенофазового анализа известняка имеют хорошую сходимость с данными химического анализа: его дифрактограмма идентифицирует наличие интенсивных отражений $CaCO_3$ с d/n = (0,302; 0,248; 0,227; 0,187...) nm (рис. 2). Присутствуют линии слабой интенсивности при d/n = (0,383; 0,208; 0,190; 0,160; 0,151; 0,143; 0,141) nm, характеризующие включения примесей алюмосиликатов калция типа геленита – $CaO{\cdot}A1_2O_3{\cdot}SiO_2$.

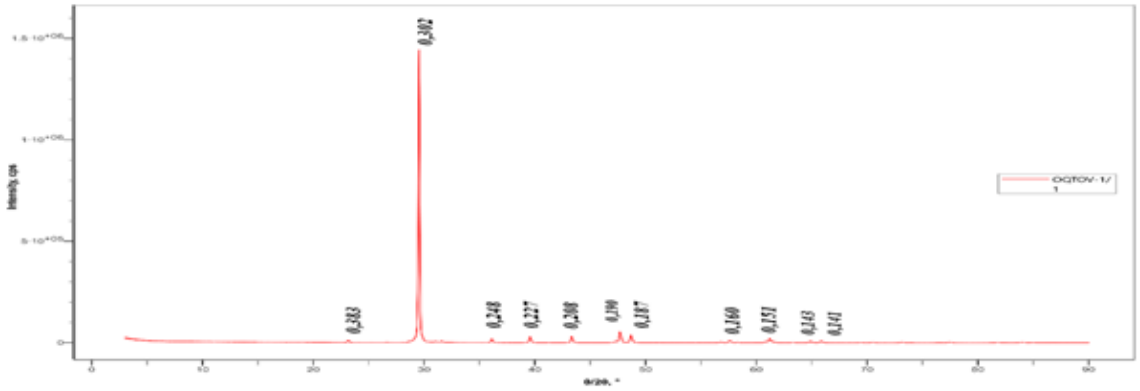

Рис. 2. Рентгенограмма технологической пробы известняка месторождения «Каракалпакстанского» участка «Oqtov», nm

Известняк, как правило, относится к числу самостоятельно не твердеющей горной породы. Поэтому его гидравлическая активность по критерию Стьюдента не определяется, а при применении его в качестве компонента композиционной добавки руководствуются требованиями ГОСТ 31108–2020, который предусматривает возможность его введения в цемент в качестве добавки-наполнителя.

В работе использован портландцементный клинкер АО «Бекабадцемент», соответствующий требованиям O‘zMSt 337:2024, гипс Каракалпакстанского месторождения участка «Тошаба» в соответствии с требованиями O‘z DSt 760 (2-й сорт), а также известняк. Химический состав исходных компонентов определяли по требованиям ГОСТ 5382–91 «Цементы и материалы цементного производства. Методы химического анализа» (табл. 1).

Таблица 1

Химический состав используемых компонентов.

Наименование	Содержание массовой доли оксидов, %							
	п.п.п	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Пр.
Известняк месторождения «Oqtov» Республики Каракалпакстан	42,80	1,05	0,80	0,75	53,68	0,44	0,20	0,28
ПЦ клинкер АО «Бекабадцемент»	0,36	21,90	4,50	3,75	64,26	1,44	-	-
	C_3S=58,25; C_2S=18,83; C_3A=5,56; C_3A+C_4AF=16,96; C_4AF=11,40; CaO/SiO_2=2,93; KN-0,90; n-2,65; p-1,20							
Гипсовый камень месторождения «Ташаба» Навоиского региона	21,17	1,15	0,78	0,17	31,60	0,34	43,46	0,39

Таблица 2

Влияние известняк на показатели прочности портландцемента

№ п/п	Сравнительные показатели прочности стандартных образцов-призм 4x4x16 см состава 1:3							
	Количество добавки (Известняк) (масс.%)	В/Ц	Сроки схватывания, h-min		В/Ц	Предел прочности при изг/сж., MPa, через:		
			начало	конец		2сут	7сут	28 сут
1	Д-0	0,26	2-02	3-02	0,5	3,3/13,22	3,9/19,92	5,55/34,91
2	Д-15	0,27	1-19	3-21	0,5	3,6/16,31	3,8/20,13	5,40/37,53
3	Д-20	0,27	1-31	3-10	0,5	2,2/12,65	3,6/19,85	4,42/33,70

При более длительном твердении цементной композиции происходит взаимодействие с $Ca(OH)_2$ с образованием гидросиликатов кальция, которые, склеивая зерна известняка в составе добавки, уплотняют формирующуюся цементную структуру и уменьшая её суммарную пористость, повышают механическую прочность, несмотря на то что доля активной клинкерной составляющей в составе портландцемента уменьшена на 20% (табл. 2).

Таблица 3

Скорость связывание воды при твердении портландцементов с 15% и 20% (Известняк)

№ п/п	Количество добавки (Известняк) (масс.%)	Содержание химически связанной воды, через (сут):			
		1	3	7	28
1	Д-0	13,73	16,10	16,27	21,38
2	Д-15	18,23	20,13	22,74	25,15
3	Д-20	18,96	21,80	22,93	24,62

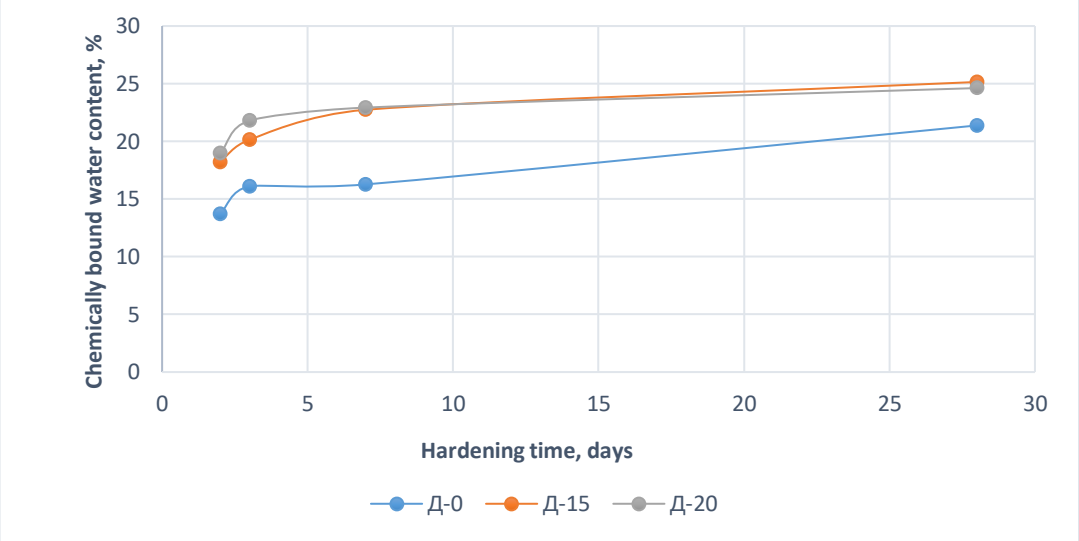

Рисунок 3. Изменение скорости гидратации портландцемента (ПЦ) в зависимости от вида известняка и времени твердения: 1-ПЦ-Д0 2-ПЦ-Д15 3-ПЦ-Д20

В таблице 3 приведены данные по кинетике связывания воды в процессе твердения портландцемента с добавкой известняка. Согласно полученным результатам, количество воды, связанной в гидратных образованиях на ранних сроках твердения как в портландцементе с добавкой известняка, так и без нее, на 1,45–1,48 % выше по сравнению с образцами из чисто клинкерного цемента.

4. Заключение

Установлено, что количество связанной воды в образцах с добавочными портландцементами несколько выше, чем у исходной матрицы, однако различия между ними незначительны. При более продолжительном твердении процесс гидратации портландцемента с известняком ускоряется, что подтверждается увеличением количества связанной воды, которое в отдельных случаях даже превышает показатель образца ПЦ-Д0.

Значения предела прочности при изгибе и сжатии образцов портландцементов с 15 % и 20 % добавки известняка в возрасте 28 суток практически не отличаются от прочностных показателей бездобавочного цемента. Полученные результаты (табл. 2) свидетельствуют о том, что при организации выпуска портландцемента с новым видом добавки достигается не только экономия до 20 % клинкерной составляющей и снижение себестоимости продукции, но и значительное увеличение объёма производства цемента.

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International engineering and landscape approaches to the planning of coastal territories in a sustainable urban environment

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Abstract: Coastal territories are increasingly recognized as key components of a sustainable urban environment due to their ecological, social, and engineering functions. However, climate-related risks and increasing anthropogenic pressure make coastal zones highly vulnerable and require integrated planning approaches. The aim of this study is to analyze international engineering and landscape approaches to coastal territory planning and to identify an integrated conceptual model ensuring ecological resilience, engineering stability, and social functionality. The methodology is based on qualitative and comparative analysis of scientific publications, analytical reports, and case studies, supported by a system approach. The results show that the most effective planning solutions are achieved through the coordinated implementation of green infrastructure, engineering adaptation, ecological regeneration, and social integration. The proposed conceptual framework can be applied in landscape and urban design practice, especially in arid and climate-vulnerable regions.

Keywords: coastal territories, sustainable urban environment, green infrastructure, landscape architecture, climate adaptation, nature-based solutions

1. Introduction

In the context of rapid urbanization, coastal territories are increasingly recognized as strategic zones of interaction between natural and anthropogenic systems. These areas perform essential ecological functions, including microclimate regulation, erosion control, and biodiversity conservation [1].

In recent decades, the impact of climate change and the growing anthropogenic pressure on urban ecosystems have significantly increased. Coastal zones are particularly vulnerable to flooding, shoreline degradation, and ecosystem instability, which necessitates the development of new approaches to their planning and management [2], [5].

Modern research emphasizes the importance of integrating engineering solutions with landscape-based approaches, particularly through the implementation of green infrastructure and nature-based solutions [3], [6], [11]. Such approaches contribute to improving ecological resilience, reducing environmental risks, and enhancing the quality of urban environments [3], [6].

However, despite the growing number of studies on coastal territory development, most existing research tends to consider engineering protection, ecological restoration, and public space organization separately. Insufficient attention is paid to their integrated application within a unified spatial and planning framework, particularly in the context of sustainable urban development and climate adaptation.

The relevance of this study is determined by the need to develop sustainable and adaptive models for coastal territory development, particularly under increasing climate risks. The integration of engineering and landscape approaches makes it possible to create multifunctional coastal environments that combine ecological, protective, and social functions.

The aim of this study is to analyze international engineering and landscape approaches to the planning of coastal territories and to identify an integrated conceptual model that ensures ecological resilience, engineering stability, and social functionality in a sustainable urban environment.

2. Research methodology

The research is based on a combination of qualitative and comparative methods. A review of international scientific publications, analytical reports, and case studies on coastal territory development was conducted.

The comparative analysis focused on identifying key approaches to coastal planning, including green infrastructure, engineering adaptation, ecological regeneration, and social integration. These approaches were evaluated according to the following criteria: ecological effectiveness, engineering resilience, adaptability to climate change, and contribution to the quality of the urban environment.

A system analysis method was applied to identify the relationships between the considered approaches and to develop an integrated conceptual model of sustainable coastal territory planning

3. Results and discussion

The analysis of international practices and theoretical approaches has made it possible to identify key engineering and landscape strategies for the sustainable planning of coastal territories. The results demonstrate that effective coastal development requires the integration of natural and engineering solutions aimed at enhancing ecological resilience, reducing anthropogenic pressure, and increasing the adaptive capacity of urban environments.

The main approaches identified in the study are summarized in Table 1.

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Table 1

Key Approaches to Sustainable Coastal Territory Planning

Approach	Main Characteristics	Expected Effects
Green Infrastructure	Use of vegetation, permeable surfaces, and natural systems	Reduction of environmental load and improvement of microclimate
Engineering Adaptation	Shoreline stabilization, drainage systems, flood protection	Increased resilience to erosion and climate risks
Ecological Regeneration	Restoration of natural ecosystems and habitats	Enhancement of biodiversity and ecosystem services
Social Integration	Development of public and recreational spaces	Improvement of urban environment quality and social accessibility

The analysis indicates that each of the identified approaches performs a distinct and complementary function within the overall system of coastal territory development. Green infrastructure contributes to microclimate regulation, water retention, and the reduction of surface runoff, thereby improving environmental performance. Engineering adaptation ensures protection against erosion processes, flooding, and other climate-related risks, providing structural stability and safety. Ecological regeneration supports the restoration of natural habitats and strengthens ecosystem services, while social integration ensures accessibility, functionality, and long-term sustainability of public spaces.

Fig. 1. Conceptual Model of Sustainable Coastal Territory Planning

The study further demonstrates that the highest effectiveness is achieved through the combined and coordinated implementation of these approaches. Their integration enables the formation of a resilient, multifunctional, and adaptive coastal environment capable of responding to contemporary environmental and climatic challenges. This is particularly important for arid and climate-vulnerable regions, where the balance between ecological processes and engineering interventions plays a decisive role in ensuring long-term sustainability.

The interrelation and interaction of the identified approaches are presented in Figure 1.

DISCUSSION

The results obtained confirm that the effective development of coastal territories requires a comprehensive approach that integrates engineering solutions with landscape-based strategies.

In contrast to traditional engineering methods focused primarily on structural protection, modern approaches emphasize the role of green infrastructure and nature-based solutions [3], [6], [8]. These approaches not only reduce environmental risks but also contribute to improving ecological stability and enhancing the quality of urban environments.

The findings of this study are consistent with current research trends in sustainable urban development, which highlight the importance of adaptive and flexible planning strategies in response to climate change and increasing anthropogenic pressure [4], [5]. These results also correspond to current approaches to urban climate adaptation and resilience planning described in international analytical reports [4], [9], [10]. Particular relevance of the identified approaches is observed in arid and semi-arid regions, where water resource management and landscape sustainability are critical factors. In such conditions, the integration of ecological and engineering solutions becomes a key factor in ensuring long-term resilience of coastal territories.

Thus, the study demonstrates that the transition from traditional engineering practices to integrated landscape-engineering approaches represents a necessary step toward sustainable urban development.

These findings are also supported by studies on spatial safety and landscape resilience in urban environments [7].

The proposed approach extends existing studies by structuring coastal planning strategies into an integrated model that combines engineering protection, ecological restoration, green infrastructure, and social functions. This synthesis allows for a more comprehensive understanding of sustainable coastal development and provides a basis for practical application in urban planning and landscape design.

4. Conclusion

The study has demonstrated that coastal territories play a significant role in the formation of a sustainable urban environment and require an integrated engineering and landscape approach.

The analysis made it possible to identify key principles for the planning of sustainable coastal territories, including the integration of green infrastructure, the application of engineering protection measures, and the implementation of nature-based solutions.

It has been established that the combination of ecological and engineering strategies enhances environmental resilience, reduces the impact of climate-related risks, and improves the overall quality of urban space.

The results of this study may serve as a conceptual basis for the development of integrated coastal planning and landscape design projects, particularly in arid and climate-vulnerable regions.

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